# CADMIUM

## A MATERIALS SURVEY

By Robert L. Mentch and Arnold M. Lansche

* * * * * * * * * * Information Circular 7881

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1958

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OFFICE OF THE DIRECTOR

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
WASHINGTON 25, D. C.

September 12, 1958

Hon. Leo A. Hoegh, Director
Office of Civil and
Defense Mobilization
New GAO Building
Washington 25, D. C.

Dear Mr. Hoegh:

Copies of the Materials Survey-Cadmium, prepared by the Bureau of Mines, are being forwarded to your office.

This report is one of the Materials Surveys to be completed under the terms of the April 15, 1955, agreement between the Department of the Interior and the Office of Defense Mobilization which assigned responsibility to Interior for preparation and the revision of Surveys covering 45 commodities. The Cadmium report is the fifteenth mineral commodity to be surveyed by the Bureau of Mines, the first twelve having been prepared under an agreement made in 1950 with the National Security Resources Board.

Manuscript revisions proposed by reviewing officials of the Office of Defense Mobilization have been incorporated in the Survey.

Sincerely yours,

Thos. H. Miller

Acting Director

III

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## *Foreword*

The Materials Survey series is being prepared to provide comprehensive fundamental data on strategic and critical materials required for military and essential civilian consumption. The data are for use primarily by Government officials responsible for the national security. This volume covers the commodity cadmium.

This report was prepared under the general direction of Charles W. Merrill, chief, Division of Minerals, Bureau of Mines, United States Department of the Interior, and under the direct supervision of Richard H. Mote, chief, Branch of Base Metals.

The element cadmium and its compounds are used in a variety of ways; major emphasis is placed on the metal in this work. A cutoff date of December 31, 1955, has been established for this survey. Information pertaining to later periods has not been incorporated.

CHARLES W. MERRILL,
*Chief, Division of Minerals.*



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# CADMIUM[1]

## A MATERIALS SURVEY

BY

ROBERT L. MENTCH[2] AND ARNOLD M. LANSCHE[3]

## *Summary and Introduction*

CADMIUM is one of the metals apparently destined to remain relatively scarce. The entire supply of primary cadmium is recovered as a byproduct, concurrently with the treatment of ores of other metals. Development of the cadmium industry is attributed to metallurgical improvements in the zinc industry; output depends almost wholly upon zinc production.

Cadmium is a metal of specialized uses where its superior performance has developed a strong, expanding demand. The supply, however, has been relatively unresponsive to price because of its byproduct nature. Cadmium's outstanding properties would assure it a manyfold greater market if more were available at lower prices.

Cadmium is a soft, malleable, ductile, bluish-white metal. It was discovered in Germany in 1817, and for 100 years Germany was the only important producer. Production in the United States began in 1906; but it was not until after World War I that cadmium came into wide use, and the United States became the largest producer.

No ore is mined solely to recover cadmium. The most common mineral, greenockite (cadmium sulfide), occurs chiefly as a yellow stain or coating on zinc sulfide ores. Cadmium minerals are also found with lead and copper ores containing zinc mineralization. Most important zinc deposits in the United States contain cadmium in varying quantities. Zinc concentrates containing as much as 1 percent cadmium are unusual.

There are no commercial reserves of cadmium ore anywhere in the world, as far as known. The entire output of primary metal is recovered as a byproduct in smelting and refining zinc-bearing ores; hence, cadmium reserves are related to zinc-ore reserves and the cadmium content of such reserves.

Cadmium metal is recovered from the flue dusts of zinc-concentrate roasting furnaces and copper- and lead-smelting plants, from zinc collected in distillation in zinc retorts, and from the high-cadmium precipitate obtained in purifying zinc electrolyte at electrolytic zinc plants. The metal is recovered by a variety of methods, most of which include the following steps: (1) Leaching the cadmium fume, dust, or residue with sulfuric acid and other reagents; (2) filtration; (3) precipitation of cadmium as a sponge by controlled addition of zinc dust; and (4) distillation in retorts or sponge leaching and electrolysis.

[1] Work on manuscript completed April 1958.
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Cadmium is used chiefly in electroplating, pigments, and low-melting-point alloys; about 95 percent of the available cadmium is consumed for these purposes, and electroplating is by far the principal use. It is also used in long-life nickel-cadmium storage batteries and in atomic energy development, where it is employed to control the fissionable elements in some nuclear reactors.

In the electroplating industry cadmium sometimes can be replaced by zinc or nickel-chromium. Tin and bismuth may be used in place of cadmium in low-melting alloys; in bearings tin is serviceable as a substitute. Lead, zinc, and barium chromates can replace cadmium sulfide as a pigment material. In nuclear-fission control boron can be used in place of cadmium.

The United States is the world's largest producer of cadmium metal, by a wide margin; approximately two-thirds of the total world output is produced at domestic plants. United States production, however, is not solely from domestic materials. It is estimated that, since 1940, about 60 percent of the primary cadmium produced in the United States was of foreign origin, obtained from imported flue dust and imported zinc, lead, and copper ores and concentrates.

World production of primary metallic cadmium totaled about 17.9 million pounds in 1955. World consumption was estimated at approximately 14.3 million pounds.

The United States, followed by Mexico, Peru, South-West Africa, Canada, Australia, the United Kingdom, Belgium, and Poland, are the leading producers of cadmium-bearing raw materials. Mexico and South-West Africa do not produce refined metal; cadmium flue dust and concentrates containing cadmium are exported to other countries.

The principal consumers of cadmium are the United States, the United Kingdom, France, Germany, Italy, Sweden, Canada, and the U. S. S. R.

The cadmium industry in the United States is composed of primary producers, secondary producers, distributors, and consumers. Primary producers supply over 95 percent of the total annual output of cadmium.

The primary producers of cadmium are, without exception, the leading producers of zinc. Eleven companies produce primary metallic cadmium at 13 plants in the United States; the largest is the American Smelting & Refining Co.

Several companies recover secondary cadmium metal and compounds from old bearings and other alloys and secondary residues. Production is comparatively small.

Distributors or dealers occupy an important position in the cadmium industry. They buy the metal from the primary producers and sell to consumers. Some distributors produce cadmium plating salts and provide technical service for their customers, who are chiefly electroplaters.

There are thousands of consumers of cadmium in the United States; most of them use relatively small quantities of the metal. The largest group of consumers is composed of companies that use the metal for electroplating. Bearing manufacturers, pigment producers, and solder makers are other major consumers.

The cadmium industry in foreign countries is similar to that in the United States.

The United States Government regulated the domestic cadmium industry during World War II and during part of the Korean conflict in 1951–52 to provide adequate supplies for all essential purposes. Public Law 520, 79th Congress, 1946, classified cadmium as a strategic and critical material for stockpiling.

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# HISTORICAL REVIEW

Cadmium was discovered in 1817 by F. Strohmeyer, a professor of metallurgy at Göttingen, Germany. Strohmeyer noticed that a sample of zinc carbonate from the zinc works of Salzgitter was slightly yellow, although it contained no iron. He attributed the color to contamination by a new element and found indication of its presence in zinc and zinc oxide from other places. In 1818, K. S. L. Hermann of Schonebeck, while examining a piece of zinc that had been rejected because of the formation of a yellow precipitate when it was dissolved in acid and saturated with hydrogen sulfide (indication of arsenic), discovered that a new element was the cause. W. Meissner confirmed Strohmeyer's and Hermann's discovery of the new element. C. J. B. Karsten of Berlin also discovered cadmium about the same time in Silesian zinc ores and wanted to call it "melinum" from "melinus," meaning quince, because of the yellow color of the sulfide. Other names suggested were "junonium," in honor of the discovery of the asteroid Juno in 1804, and "klaprothium," in honor of M. H. Klaproth. However, Strohmeyer proposed "cadmium" from "cadmia fornacum," due to the fact that the element collects in the flowers of zinc found in dust from zinc furnaces, and his proposal was generally accepted.

For more than 60 years after its discovery, few applications were found for cadmium; and, because of its association with zinc, it was frequently referred to as "the unwanted stepchild of zinc." It was first used in the sulfide form in paint pigments. The earliest uses for cadmium were the following: Low-melting alloys, for electroplating iron and steel, and as salts in dentistry, dyeing and calico printing, glassmaking, photography, and chemical reagents.

The first commercial cadmium was produced in Germany in the 19th century, and until 1911 Germany was the only important producer, obtaining the metal as a byproduct of the smelting of cadmium-bearing zinc ores of Upper Silesia. World production during this period was relatively small; it reached a peak of about 100,000 pounds in 1910, with Germany accounting for more than 90 percent of the total. Belgium also produced small quantities of metal during the early years of cadmium production.

Cadmium was first produced in the United States in 1906 on a pilot-plant scale. In 1907 the Grasselli Chemical Co. of Cleveland, Ohio, recovered commercial quantities of the metal—14,000 pounds—as a byproduct of zinc smelting. In 1910 American Smelting & Refining Co. began production at its Globe lead smelter in Denver, Colo. Thereafter other companies entered the field, and by 1925 cadmium was being produced at 10 plants in the United States, including 6 lithopone or chemical plants, 3 lead smelters, and 1 electrolytic zinc plant. Production in the United States increased rapidly when German sources were cut off in World War I; new uses for the metal were discovered, and improved recovery techniques were introduced. In 1917 the United States produced 207,000 pounds, becoming the world's leading producer, a position that it has retained ever since, except for 1918.

Contributing to the increased use of cadmium after World War I was development of the cadmium-electroplating process of the Udylite Process Co., Kokomo, Ind., by Marvin J. Udy. The first patent relating to cadmium plating was issued in England in the 1840's, but plating with cadmium did not come into widespread use until after 1919, following the work of Udy. Use for electroplating soon became the most important application of cadmium metal, and by the 1940's it represented approximately three-fourths of the total consumption. The increased demand for cadmium led to greater production, and by World War II the output of primary cadmium at United States plants exceeded 8 million pounds a year—about 40 times higher than production in 1917.

# OCCURRENCE

Cadmium is a relatively rare element; its abundance in the lithosphere is estimated at only 0.5 gram per ton in the earth's crust. Cadmium minerals have not been found in commercial quantities; hence no ore is mined solely for the recovery of cadmium. The most common mineral, greenockite (cadmium sulfide—77.8 percent cadmium) occurs chiefly as a yellow stain or coating on the zinc sulfide (sphalerite). Cadmium minerals are also found with



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lead and copper ores containing zinc, but it is generally accepted that the cadmium in such ores is associated with the zinc rather than the other metals. Cadmium metal is recovered almost entirely from zinc sulfide ores or other sulfide ores, principally lead and copper, containing zinc mineralization. Cadmium oxide has been detected in a few instances as a coating on hemimorphite ($Zn(OH)_2SiO_3$) crystals.

# RESERVES

## UNITED STATES RESERVES

There are no commercial reserves of cadmium ore, as such, in the United States. It is recovered as a byproduct in connection with the smelting and refining of zinc-bearing ores; hence cadmium reserves depend upon the size of zinc-ore reserves and their cadmium content.

An estimate by the Federal Geological Survey in 1944 placed the recoverable cadmium in domestic reserves of zinc ore of all grades (measured, indicated, and inferred) at 100 million pounds (*47*).[4] Estimates of zinc-ore reserves in 1950 (*74*) indicate approximately the same quantity of recoverable cadmium as in 1944.

Domestic cadmium reserves may be considerably greater than 100 million pounds and, conversely, substantially less than that figure, depending on the magnitude of zinc-ore reserves (and to a limited extent lead- and copper-ore reserves), which in turn are contingent upon changing economic and technologic factors. Zinc-ore reserves, which constitute the basis for cadmium-reserve estimates, are listed in table 1.

Nearly all major zinc deposits in the United States contain cadmium in quantities ranging from less than 0.01 percent to a high of about 1 percent. The principal exception is the ore body at Franklin and Sterling Hill, N. J., where only traces of cadmium are found. Zinc concentrates containing as much as 1 percent cadmium are very unusual; the content averages less than 0.5 percent. Zinc concentrates from the Tri-State area of Missouri, Oklahoma, and Kansas average about 0.35 percent cadmium, and concentrates from mines in the Western States rarely carry more than 0.25 percent cadmium.

Zinc concentrates, including both domestic and foreign materials processed at the Kellogg (Idaho) electrolytic zinc plant of The Bunker Hill Co., average about 0.24 percent cadmium. The cadmium content of zinc concentrates from the Coeur d'Alene district (Idaho) ranges from 0.15 to about 0.32 percent. Typical cadmium contents of zinc concentrates from the Holden and the Metaline Falls areas of Washington average 0.35 and 0.15 percent, respectively (*84*).

Domestic ores carrying the highest percentage of cadmium occur in the Southeastern Missouri lead district and the Southern Illinois-Kentucky zinc-lead-fluorspar region. Bureau of Mines analyses of zinc concentrates treated at the Leadwood (Mo.) mill of the St. Joseph Lead Co. showed a cadmium content of 1.29 percent and average cadmium values of about 0.9 percent for zinc concentrate from the Minerva Oil Co. Zinc production from these two regions is small, however, totaling only a few thousand tons annually; hence, cadmium recovery is also small compared with that of other areas.

A study by the War Production Board in the Tri-State district during World War II indicated an average recovery of about 7.4 pounds of cadmium per ton of recoverable zinc. Studies on the yield of cadmium from western ores showed that, in many instances, western ores yielded as much cadmium as those from the Tri-State area. Usually, however, the yield was smaller. The plants in the Eastern States showed a recovery of less than 2 pounds of cadmium per ton of zinc. The average yield of all domestic ores was estimated at about 4.25 pounds of recoverable cadmium per ton of recoverable zinc. Production records, however, particularly in recent years (1949–55), indicate a recovery of about 6 pounds of cadmium per ton of recoverable zinc.

## FOREIGN RESERVES

The total cadmium reserve in foreign countries greatly exceeds that in the United States. Based on world zinc reserves (exclusive of the United States) and estimating a recovery of 12 pounds of cadmium per ton of recoverable zinc, foreign cadmium reserves aggregate about 1,908 million pounds.

Mexico, Canada, Australia, Peru, South-West Africa, Japan, Italy, and Germany are the chief Free World sources of cadmium outside the United States. These countries are important zinc producers and have large reserves of both zinc and cadmium. Other sources of cadmium include Argentina, Bolivia, Chile, Belgian Congo, Northern Rhodesia, Norway, Spain, and Yugoslavia. The cadmium content of ores mined varies consid-

[4] Italicized figures in parentheses refer to items in the bibliography at the end of this report.

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TABLE 1.—*Estimated zinc reserves of the United States as of January 1950*

(Thousand short tons of metallic zinc)

[Federal Geological Survey]

| | Measured and indicated | | Inferred | | Total | |
|---|---|---|---|---|---|---|
| | Gross content | Recoverable content [1] | Gross content | Recoverable content [1] | Gross content | Recoverable content [1] |
| Zinc in deposits that could be worked under technologic conditions similar to those in 1950 | 8, 480 | 6, 530 | 12, 700 | 9, 800 | 21, 200 | 16, 300 |
| Zinc in deposits workable under possible future technologic or industrial conditions | 3, 440 | ---------- | 400 | ---------- | 3, 800 | ---------- |

[1] Milling and smelting losses considered to be 23 percent.

erably. South-West Africa probably has the richest ores; zinc concentrates contain about 1.5 percent and lead-copper concentrates about 0.5 percent cadmium. Data showing zinc reserves of some important producers and the pounds of cadmium obtained per ton of recoverable zinc are given below:

| Country: | *Zinc reserves (thousand short tons)* | *Cadmium (pounds per ton of recoverable zinc)* [1] |
|---|---|---|
| Mexico | 1, 000 | 14. 6 |
| Canada | 8, 000 | 4. 1 |
| Australia | 12, 500 | 4. 5 |
| Peru | 4, 000 | 8. 4 |
| Bolivia | 700 | 10. 8 |
| Argentina | 1, 500 | 6. 7 |
| Belgian Congo | 1, 400 | 13. 0 |
| South-West Africa | [2] 700 | ([3]) |

[1] Based upon a report prepared by the Board of Economic Warfare, Jan. 26, 1943, and revised by the War Production Board, August 1943.
[2] Zinc, lead, and copper.
[3] Zinc concentrates contain up to about 1.5 percent cadmium and lead-copper concentrates up to about 0.5 percent cadmium.

Mexico probably has much more than 1 million tons of zinc reserves; hence, cadmium reserves are large and important, particularly because of the high cadmium content of the ores. Recent zinc and lead discoveries in Canada prompt the belief that Canada will soon become even more important as a source of cadmium than at present. Important lead and zinc finds have been made in French North Africa since the end of World War II. The cadmium content of the ores, however, is rather low; zinc concentrate from Zellidja, the largest deposit, assays less than 0.20 percent cadmium.

Studies of Metals Reserve Company contracts with The Anaconda Company for treating zinc concentrate and subsequent recovery of cadmium during World War II show the quantities of cadmium contained in zinc concentrate from many foreign districts. The average cadmium content of zinc concentrate from some of the more important zinc-producing districts for the period 1942–46 is given below:

| District: | *Average cadmium content of zinc concentrates (percent)* |
|---|---|
| *North America* | |
| El Potosi, Mexico | 0. 61 |
| Santa Eulalia, Mexico | . 60 |
| Fresnillo, Mexico | . 50 |
| Western Exploration, Canada | . 40 |
| Sheep Creek, Canada | . 30 |
| Mattie Mill, Canada | . 28 |
| Retallack, Canada | . 28 |
| Twin J, Canada | . 22 |
| Sherritt Gordon, Canada | . 17 |
| Base Metals, Canada | . 10 |
| *South America* | |
| Cercapuquio, Peru | 1. 38 |
| Atacocha, Peru | . 33 |
| Cerro de Pasco, Peru | . 18 |
| Huaron, Peru | . 17 |
| Huanchaco, Bolivia | . 27 |
| *Australia* | |
| Broken Hill | . 20 |
| Mount Isa | . 16 |
| Lake George | . 14 |

Recovery of cadmium from zinc concentrates from the above districts ranged from about 62 to 72 percent, depending chiefly on the composition of the concentrates. Production of cadmium, in relation to zinc-metal production from these districts, taking into consideration the zinc content of concentrates (which varied from about 48 to 61 percent), averaged about 18 pounds of cadmium per ton of recoverable zinc for Mexico, 8 pounds per ton for Peru, 4.4 pounds per ton for Australia, and 8 pounds per ton for western Canada. These values are approximations for certain districts in these countries during the period 1942–46 and are not

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valid for the entire zinc production of these countries. In the Canadian Province of Quebec—a large zinc producer—the cadmium content of zinc concentrates averages about 0.20 percent, ranging from a low of 0.10 to a high of 0.35 percent (*85*).

Estimates of cadmium production in the United States from domestic and foreign sources are given in tables 6 and 7 (p. 27).

Poland has been a major source of cadmium for many years and, with the World War II addition of Germany's Upper Silesia (which contains large zinc (and cadmium) reserves), has become a very large producer.

The U. S. S. R. has fairly large potential reserves of cadmium. Production, however, was small before World War II, and with destruction of the bulk of its cadmium-smelting facilities in the war, Russia depended almost completely upon foreign supplies of the metal. Since the war availability of important cadmium resources from Poland, plus a revived domestic output, have eased this deficiency. Shimkin (*83*) gives the potential production of cadmium in the U. S. S. R. in 1937 as follows:

| Deposits | Zinc content of ore mined, short tons | Cadmium per ton of recoverable zinc, pounds | Possible Cd recovery | |
|---|---|---|---|---|
| | | | Percent | Short tons |
| Ridder, Belousovka, Zyryanovsk | 37,400 | 4 | 20 | 14.9 |
| Turlan, Kansai | 15,500 | [1] 10 | 50 | 38.7 |
| Sadon | 19,200 | 8 | 40 | 30.7 |
| Chelyabinsk | 21,200 | [2] | | |
| Salair | 16,800 | [1] 10 | 50 | 42.0 |
| Tetyukhe | 14,300 | 10 | 50 | 35.7 |
| Total | 124,400 | | | 162.0 |

[1] Estimated. [2] Copper-zinc ores.

Total Soviet cadmium resources, as of January 1936, are also estimated (*83*). These are given below, in short tons.

| Economic region | Cadmium contained in measured zinc-ore reserves | Cadmium contained in total zinc-ore reserves |
|---|---|---|
| Turkestan | 2,980 | 9,590 |
| Eastern Siberia | 1,400 | 1,650 |
| Far East | 1,650 | 2,920 |
| Transcaucasus | 770 | 3,400 |
| Western Siberia | 830 | 1,100 |
| Total U. S. S. R. (approximate) | 7,630 | 18,660 |

# RECOVERY OF CADMIUM

The entire domestic supply of primary cadmium is recovered concurrently with the treatment of ores of other metals as a byproduct from the flue dusts of zinc-concentrate roasting furnaces and sintering machines and copper- and lead-smelting plants, from zinc collected in distillation in zinc retorts, and from the high-cadmium precipitate obtained in purifying zinc electrolyte at electrolytic zinc plants. Other metals, principally germanium, thallium, and indium, are also found in zinc-plant flue dusts and commonly recovered as byproducts.

Cadmium and cadmium compounds have, in general, lower melting and boiling points than do zinc and the analogous zinc compounds; furthermore, cadmium oxide can be reduced more easily than zinc oxide. These differences are the basis for recovering cadmium as a byproduct of zinc smelting or from lead or copper smelting where zinc and cadmium are present.

The first commercial process for recovering cadmium was a crude separation during reduction of zinc in a retort. Roasted zinc ore, mixed with coke or coal, was charged to a retort, which was connected to a primary condenser and a secondary condenser or "prolong." The roasted zinc ore was reduced by externally applied heat, the zinc and cadmium were vaporized, and the bulk of the zinc and some of the cadmium were condensed in the first condenser. Most of the cadmium was not caught in the primary condenser, owing to its lower boiling point, but was condensed in the prolongs as "blue powder." The blue powder, containing 3 to 5 percent cadmium, was again reduced with coal or coke and redistilled to give fairly pure cadmium metal and some cadmium powder. The powder was returned for reduction and distillation. This process was very inefficient, giving low yields of metal and requiring considerable labor. The present emphasis in zinc-retort plants is on recovery from the roasting operations and from the zinc metal itself, rather than from the blue powder produced in retorting operations.

Bureau of Mines investigations (*76*) to develop methods and determine conditions under which metallic sulfides with lower boiling points than sphalerite might be removed from zinc sulfide concentrates by volatilization showed that over 90 percent of the lead, cadmium, and germanium can be removed as enriched sublimate. A higher percentage of extraction of these metals than is common in current practice was sought.

Although 0.5 to 3 percent of the zinc was also volatilized, the volatile product was greatly enriched in lead, cadmium, and germanium. The experiments were performed over a temperature range of 700° to 1,050° C. The material was volatilized in a partial vacuum, in

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an inert atmosphere, and in a reducing atmosphere, with the highest extractions attained in experiments utilizing the partial vacuum and the reducing atmosphere.

Further investigations were being directed toward separation of the fumed sulfides of cadmium, germanium, and lead by selective volatilization.

## HORIZONTAL ZINC-RETORT PLANTS

Cadmium is recovered at four horizontal zinc-retort plants in the United States—Fairmont City, Ill. (American Zinc Co. of Illinois); Henryetta (Eagle-Picher Co.) and Bartlesville (National Zinc Co., Inc.), Okla.; and Donora, Pa. (U. S. Steel Corp., American Steel & Wire Division).

The processes employed are much alike and consist essentially of the following steps:

(1) Roasting the zinc concentrate to oxidize the zinc and sulfur. In this operation some of the cadmium is volatilized and collected as dust or fume, normally containing 3 to 5 percent cadmium, in baghouses and electrostatic precipitators.

(2) Sintering the resulting calcines and dust along with cadmium-furnace residues, a mixture of zinc chloride and zinc sulfate liquor, and coke or coal. When the fuel burns, it provides a high temperature in the bed, and the chlorides react with the cadmium, lead, and other impurities; these impurities are volatilized and collected, usually in an electrostatic precipitator. The zinc is not appreciably affected at the sintering temperature and remains with the sinter. The fumes may contain as much as 25 percent cadmium, depending on the quantity of cadmium in the original sinter.

(3) Leaching the Cottrell dust from sintering, usually with sulfuric acid, sodium chlorate, and water. Any lead present is precipitated as lead sulfate, and some other impurities are separated by chemical means, leaving only cadmium and copper (and sometimes arsenic) in the solution.

(4) Fractional precipitation of the cadmium and copper as sponges by the addition of zinc dust.

(5) Distillation of the prepared sponge in a horizontal batch-type retort, yielding cadmium metal, blue powder, and residue.

Some plants vary this procedure. In sintering, the cadmium that is not drawn off as fume into the baghouse tends to concentrate in the lower section of the sinter bed, leaving the upper section of the sinter relatively free of cadmium. To take advantage of this fact, a so-called "sinter cutter" is built into the conventional Dwight-Lloyd machine at the discharge end. As the sinter cake progresses along on the moving pallets, a cut of calculated depth is taken and moved to a discharge point. This product is the finished sinter for the zinc-reduction retorts. The lower section of the sinter cake high in cadmium passes on and is discharged at the end of the machine. After crushing, it is returned to the charge.

The presence of arsenic in many flue dusts and residues necessitates extreme caution and adequate ventilation, since conditions are very favorable for the formation of arsine—especially when zinc dust is used with an acid solution. Inhalation of even small quantities of this gas can result in death; hence, rigid safety measures are mandatory.

The quantity of zinc dust added to precipitate the cadmium as sponge depends somewhat on the final purification step (*78*).

If the cadmium is to be treated by pyrometallurgical means, the addition of zinc dust to the liquor is controlled to give a nearly pure cadmium sponge; this is done by incomplete precipitation of the cadmium. The remaining cadmium in the liquor is recovered by recycling of the liquor. The cadmium sponge is briquetted to reduce oxidation losses and charged to a retort. If necessary, a little coke is added for reduction of any oxide. The cadmium is distilled from the retort and subsequently redistilled under carefully controlled conditions to obtain pure cadmium. This pure cadmium is remelted under a layer of caustic soda and cast into appropriate shapes.

Where the cadmium is to be recovered by electrolytic methods, a certain amount of zinc can be tolerated in the electrolytic cells. Hence, excess zinc dust is added to the cadmium-bearing solution to precipitate all of the cadmium and the purified zinc-cadmium sponge used for the raw feed to the electrolytic cells.

An outline of the process employed at the American Zinc Co. of Illinois plant at Fairmont City, Ill., for recovering cadmium from zinc ores and concentrates is shown in figure 1.

## VERTICAL-ZINC-RETORT PLANTS

Cadmium may also be recovered directly from cadmium-bearing zinc metals by direct distillation. The process is, in effect, an adaptation of the standard chemical engineering principles of rectification and was introduced by the New Jersey Zinc Co. in its development of the vertical-retort process for producing zinc of a quality comparable to that yielded by electrolytic methods. Employing the principles of rectification in this distillation, high-boiling-point impurities (such as lead) and low-boiling-point impurities (such as cadmium) can be separated from relatively impure zinc and a zinc metal of 99.99-percent purity recovered by strictly pyrometallurgical means. Inasmuch as cadmium is removed and recovered, this process has significance in commercial production of cadmium.

Molten zinc, which constitutes the feed for the fractionating columns in this process, con-

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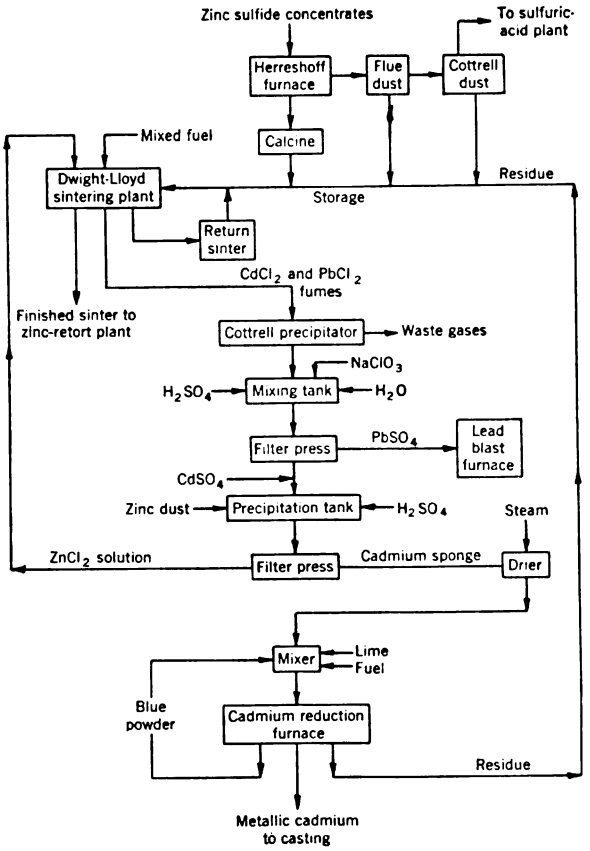


(Courtesy, American Zinc Co. of Illinois.)

FIGURE 1.—Flowsheet of Fairmont City (Ill.) Plant, Showing Recovery of Cadmium in Roasting of Zinc Ore.

tains both lead and cadmium. Lead has a boiling point of about 1,620° C., zinc 905° C., and cadmium 767° C. None of these elements forms constant-boiling-point mixture or stable compounds with each other that vaporize without dissociation; therefore, they lend themselves to separation by fractional distillation.

The New Jersey (Sterling) process combines initial bulk distillation in a vertical retort and purification of the crude metal in fractionating columns, where the cadmium is recovered. In purification, the molten crude metal is charged to a lead-rectification column, where—by a series of fractionations—zinc and cadmium are distilled off lead-free and condensed, while a high-lead-zinc alloy is drawn off at the bottom of the column. The molten zinc-cadmium condensate from the lead column is run into a cadmium-rectification column, where the cadmium is distilled and condensed. The cadmium is then purified and cast into commercial shapes. Refined liquid zinc is continuously drawn off from the bottom of this column. This process is employed at the New Jersey Zinc Co. Depue (Ill.) and Palmerton (Pa.) vertical-retort plants. The enriched cadmium dust obtained at Palmerton is shipped to Depue for metal recovery. Figure 2 shows, in diagrammatic form, a unit for the practical operation of direct cadmium distillation.

Cadmium is produced at the St. Joseph Lead Co. electrothermic zinc plant (vertical retort) at Josephtown, Pa., by more conventional methods. Cadmium in flue dust is taken into acid solution, from which it is precipitated with zinc dust to yield crude sponge cadmium. The sponge is dried, oxidized, redissolved in sulfuric acid, purified by controlled additions of zinc dust, filtered, and pumped to a cementation tank, where relatively pure cadmium sponge is produced from metathesis with slabs of zinc. The sponge is caked and distilled in graphite bottles, and the distillate is melted and cast into marketable shapes.

## ELECTROLYTIC PLANTS

The electrolytic production of cadmium first assumed importance in the United States about 1915 as a result of introduction of the electrolytic zinc process, because removal of cadmium from the zinc electrolyte is a necessary purification step before electrolysis. The high-cadmium precipitate obtained in this purification, as well as baghouse fume from zinc roasting and lead and copper smelters, is processed in electrolytic cadmium plants.

Cadmium-recovery units are in operation at five electrolytic zinc plants in the United States—Great Falls, Mont. (The Anaconda Company); Monsanto, Ill. (American Zinc Co. of Ill.); Corpus Christi, Tex. (American Smelting & Refining Co.); and Kellogg, Idaho (The Bunker Hill Co.). Of these plants, Great Falls, Kellogg, and Corpus Christi produce refined metal, and Monsanto produces a high-cadmium sponge, which is shipped to Fairmont City for refining. In addition, metallic cadmium is recovered by electrolytic means at the Globe (Denver, Colo.) cadmium plant of the American Smelting & Refining Co.

In the electrolytic-zinc process cadmium and copper are taken into solution with the zinc in the sulfuric acid leach of the roasted zinc ore. These elements are interfering impurities and must be removed before the leach liquor can be sent to the zinc cells. Zinc dust is added to precipitate many of the objectionable elements. Precipitation usually is conducted in two steps. In the first, a limited quantity of zinc dust is used to give a high-copper precipitate; in the second, an excess of dust is added to the filtrate from the first step,

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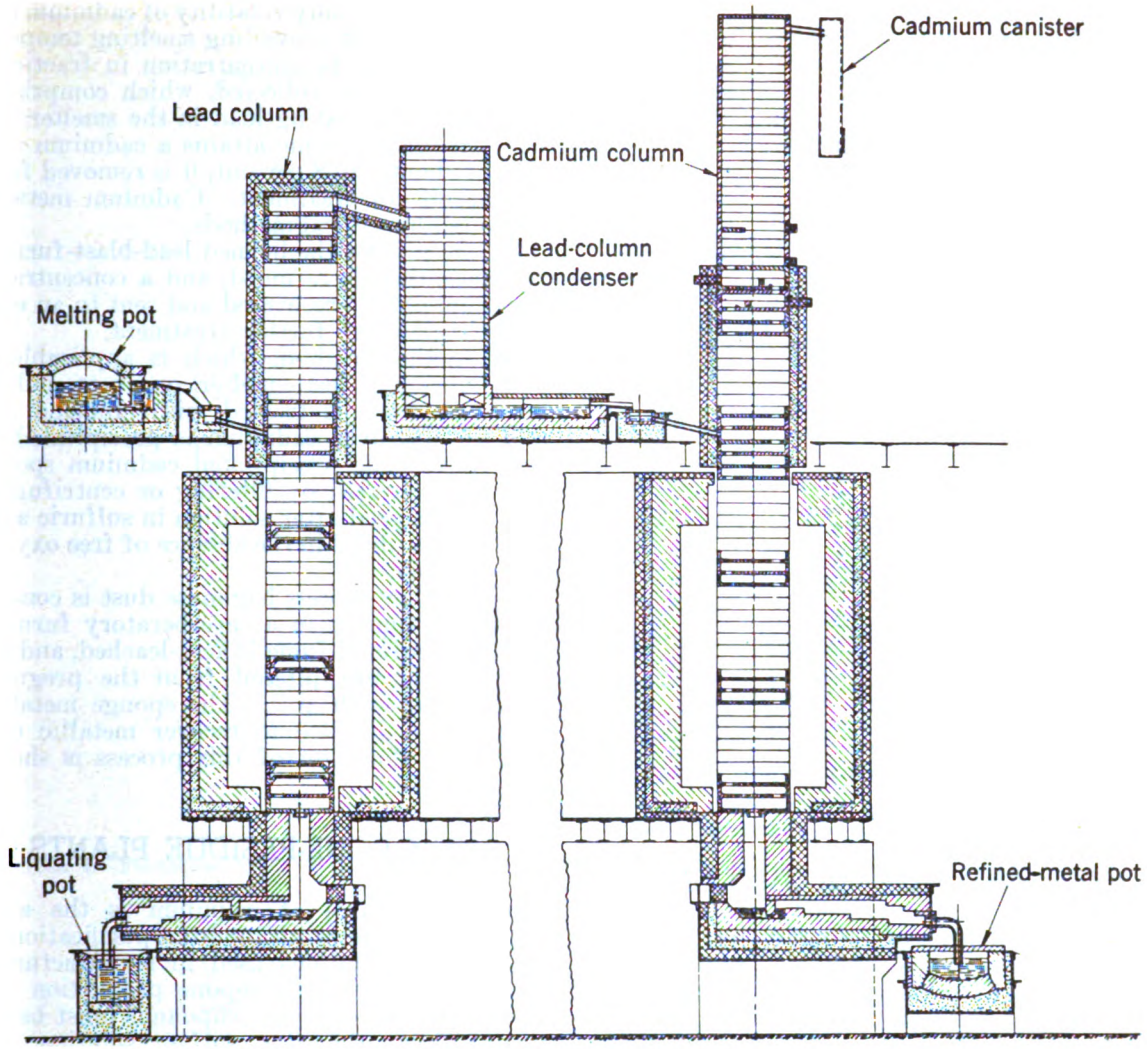


(Courtesy, The New Jersey Zinc Co.)

FIGURE 2.—Flowsheet of Sterling Process, Showing Separation of Cadmium and Lead From Zinc by Distillation.

yielding a zincky, high-cadmium precipitate, which constitutes the feed for the cadmium plant. The cadmium is leached from this precipitate; after various separation steps, a cadmium sulfate solution is electrolyzed to produce electrolytic cadmium, which is then melted and cast into commercial shapes.

In more detail, the cadmium-plant operations consist of (1) leaching the precipitate from the second-stage zinc-solution purification tanks with sulfuric acid and return cadmium electrolyte; (2) filtration, which yields a high-copper cake and a filtrate containing about 120 grams per liter of cadmium and 110 of zinc; (3) precipitation of cadmium as sponge by controlled addition of zinc dust; (4) oxidation; (5) sponge leaching with sulfuric acid, condensate water, and cadmium spent solution; and finally (6) electrolytic deposition of cadmium from the filtrate.

Cells are lead-lined and similar in size and construction to those used in zinc plants. The solution is electrolyzed at 2.6 to 2.7 volts and 4 to 10 amperes per square foot, using aluminum cathodes and chemical lead or Duriron anodes. Glue is used to reduce the tendency of cadmium to deposit in irregular shapes. Cathodes are stripped regularly, and the cadmium is washed, dried, melted in an iron pot under caustic soda or rosin to prevent excessive oxidation, and cast into desired shapes.

Figure 3 is a generalized flowsheet of the process employed for the electrolytic production of cadmium.

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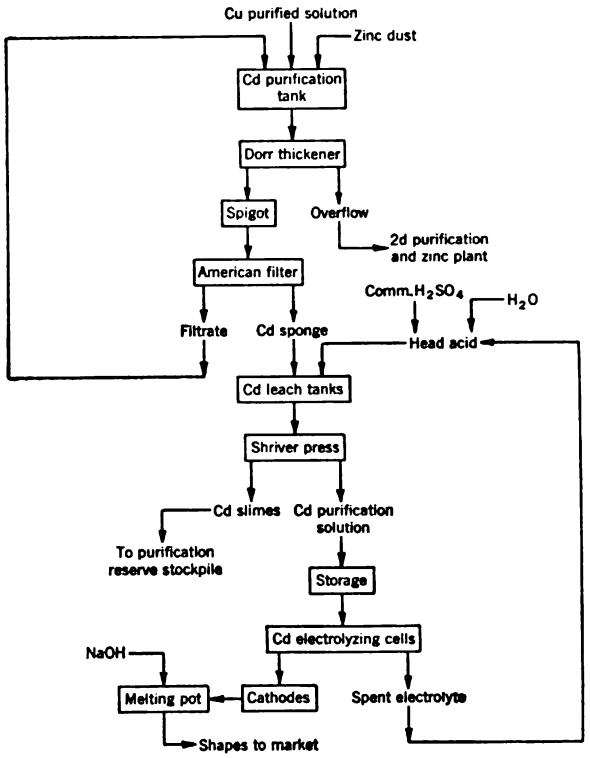


(Courtesy, The Anaconda Company)

FIGURE 3.—Flowsheet of Great Falls (Mont.) Plant, Showing Production of Cadmium.

## LEAD AND COPPER SMELTERS

Important sources of cadmium are the baghouse dust and fume from lead and copper smelters operating on zincky ores containing cadmium. Metallic cadmium is produced at two lead smelters, one at Herculaneum, Mo. (St. Joseph Lead Co.), and the other at Bradley, Idaho (The Bunker Hill Co.).

The cadmium content of lead and copper concentrates is very low; and, were it not for the marked tendency of cadmium to volatilize during roasting and smelting, the small concentrations present would be lost in the large tonnages of blast-furnace slag and other smelter products. The ready volatility of cadmium and its compounds at prevailing smelting temperatures results in its concentration in fractional portions of fume collected, which comprise a continuous circulating load in the smelter system. When the fume attains a cadmium content of about 3 to 8 percent, it is removed from the circuit for treatment. Cadmium metal is recovered by several methods.

In one process the burned lead-blast-furnace baghouse dust is refumed, and a concentrated cadmium dust is recovered and sent to an electrolytic plant for further treatment.

In another method, which is applicable to both zinc- and lead-smelter products, pulped baghouse fume is treated with chlorine gas, and the dissolved cadmium is precipitated by zinc dust. The precipitated cadmium sponge may be separated by filtering or centrifuging and electrolyzed after solution in sulfuric acid, or it may be dried in the absence of free oxygen and distilled.

By another process baghouse dust is concentrated by fuming in a reverberatory furnace. The concentrated fume is acid-leached, and the cadmium is precipitated from the pregnant leach liquor with zinc. The sponge metal so obtained is distilled to recover metallic cadmium. A flowsheet of this process is shown as figure 4.

## LITHOPONE-RESIDUE PLANTS

Another source of cadmium is the zinc-cadmium sludge resulting from purification of zinc sulfate solutions used in manufacturing zinc lithopone. In lithopone production elements yielding colored compounds must be removed from the zinc sulfate solution. A purification similar to that used in treating electrolytic zinc electrolyte is followed. Roasted zinc ore is leached with a sulfuric acid solution, and the cadmium is precipitated in the usual way with zinc dust. This precipitated sponge may be subjected to fractional distillation to obtain pure cadmium metal or be worked up by producers of chemical compounds.

# PROPERTIES OF CADMIUM

Cadmium is a monatomic, silver-white metal tinged with blue. When freshly cut or polished, it has a brilliant luster, which dulls upon exposure to moist air; a protective coating (consisting of the suboxide and oxide of the metal) forms on the exposed surface. It is in period V, group II, of the atomic table. The mass numbers of its naturally occurring isotopes and their abundance are 106 (1.2 percent), 108 (1 percent), 110 (12.4 percent), 111 (12.9 percent), 112 (23.8 percent), 113 (12.3 percent), 114 (28.8 percent), and 116 (7.7 percent). The mass numbers of the radioactive cadmium isotopes and their half life are 105 (38 minutes), 107 (6.7 hours), 109 (330 days), 111 (48.7 minutes), 113 (5.1 years), 115 (2.33 days; and 43 days), and 117 (40 minutes; and 2.83 hours). Cadmium ordinarily crystallizes in hexagonal

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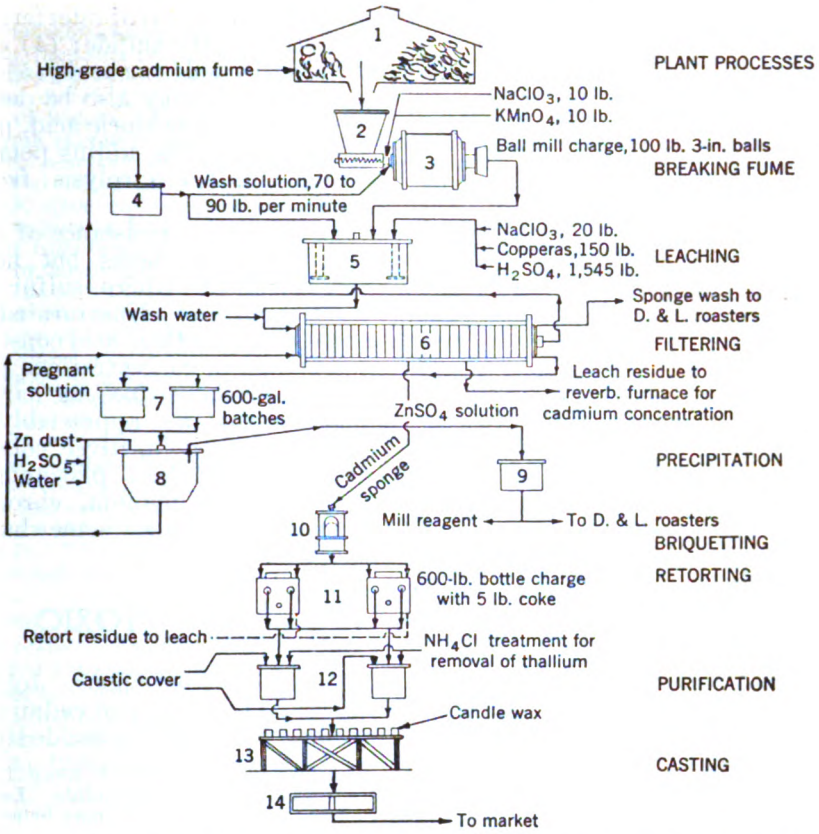


FIGURE 4.—Flowsheet of Bradley (Idaho) Plant, Showing Recovery of Cadmium From Baghouse Dust of Lead Smelters.

*1*, Storage shed; *2*, 6,000-pound batch leach with screw feeder; *3*, 3- by 3-foot ball mill; *4*, wash-solution storage tank; *5*, 8- by 8-foot lead-lined leach tank; *6*, Shriver press, 42 2-inch- by 3-foot- by 3-foot frames; *7*, 5,000-gallon pregnant-solution storage tank; *8*, 8- by 8-foot, lead-lined, precipitation tanks; *9*, zinc sulfate storage tank; *10*, briquet machine; *11*, two-bottle, oil-fired retorts; *12*, holding pots, 3,000-pound capacity; *13*, 10 4- by 16- by ¾-inch molds; *14*, cleaning and boxing section.

(Courtesy, The Bunker Hill Co.)

pyramids; regular octahedral crystals can be obtained by condensation of its vapor in a current of hydrogen.

Several of its properties make it an important commercial metal. Electrodeposited cadmium has good adherence to ferrous metals and excellent corrosion resistance, which make it a competitor of zinc as a coating material. The relatively low melting point of cadmium and its softness make it suitable for use in low-melting-point alloys. Some cadmium compounds—for example, cadmium sulfide and cadmium sulfoselenide—have properties that make them excellent pigment materials.

## PHYSICAL

The cadmium spectrum consists of brilliant red, green, and blue lines.

The density of cadmium varies with temperature and decreases as the temperature rises. The density for various temperatures in grams per cubic centimeter is as follows: 20° C., 8.65; 25° C., 8.62; 60° C., 7.72; 700° C., 7.56; 720° C., 7.54; 750° C., 7.51.

It was suspected that cadmium had different allotropic forms when it was observed that hammering cast cadmium changed its specific gravity from 8.60 to approximately 8.69. The existence of definite allotropic modifications of cadmium has since been demonstrated.

The electrical resistivity of metallic cadmium can be altered by heat and magnetism. A gradual increase in electrical resistivity is observed in the metal as the temperature is raised; and the increase is more rapid at its melting point. At 0° C. the electrical resistance is 6.83 microhm-cm., and at 700° C. about 35.8. The temperature coefficient of electrical resistivity is 0.0042 per degree centigrade at 0° C. An increase in resistivity occurs when the metal is placed in a magnetic field; the increase is proportionate to the square of the field strength.

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A list of some physical properties of cadmium and zinc is given below.

| Property: | *Cadmium* | *Zinc* |
|---|---|---|
| Atomic weight | 112. 41 | 65. 38 |
| Melting point, °C | 320. 9 | 419. 5 |
| Boiling point, do | 765 | 907 |
| Latent heat of fusion, cal. per gm | 13. 2 | 24. 09 |
| Latent heat of vaporization, cal. per gm | 286. 4 | 425. 6 |
| Specific heat, do | 0. 055 | 0. 092 |
| Thermal conductivity (100° C.), cal.-cm.²/cm./°C./sec | 0. 216 | 0. 262 |
| Hardness (Mohs scale) | 2 | 2. 5 |
| Density, 20° C., gm./cc | 8. 65 | 7. 13 |
| Electrochemical equivalent, milligrams/coulomb | 0. 582 | 0. 339 |
| Electrolytic solution potential, volt | +0. 4 | −0. 762 |
| Tensile strength, lb/sq. in | 13, 600 | 10, 000 |
| Magnetic susceptibility, $10^{-6}$ c. g. s., 18° C | −0. 18 | −0. 157 |

A discussion of the physical and chemical properties of the major cadmium salts is given on pp. 11 and 12. Table 2 lists the physical properties of the less important compounds.

## CHEMICAL

Cadmium is almost always divalent, the only two common monovalent compounds being cadmium suboxide ($Cd_2O$) and cadmous chloride ($Cd_2Cl_2$).

Cadmium is unaffected by dry air but oxidizes readily in moist air, with formation of a protective coating of oxides. It does not react with water at room temperature but reacts with hot steam to form cadmium oxide and hydrogen (reversible reaction). It burns in oxygen, air, and chlorine and combines directly with chlorine, bromine, and iodine in solutions of these elements. Most organic and some inorganic acids dissolve cadmium, nitric acid being the best acid solvent. The salts, especially the iodide, ionize slightly in most instances. Cadmium salts will not precipitate in heavily ammoniacal solutions owing to the formation of a soluble complex ion; it also forms complex cyano- and halide ions. Zinc precipitates cadmium in dendritic form from salt solutions. Cadmium is completely precipitated by aluminum from salt solutions containing a trace of chromium nitrate; it also may be deposited by electrolysis. It is not amphoteric, as is zinc, and so is insoluble in alkalis.

Cadmium in solution is detected by precipitation of the yellow sulfide with hydrogen sulfide. The sulfide is insoluble in dilute acids, ammonium sulfide, or caustic alkalis and is thus distinguished from the yellow sulfides of tin and arsenic.

Cadmium may be quantitatively determined by the following process: (1) Dissolving the metal; (2) removal of interfering ions; (3) precipitation as the sulfide; (4) conversion to the sulfate with sulfuric acid; (5) evaporation and weighing. It may also be determined by dissolving in hydrochloric acid, neutralizing with sodium hydroxide, adding potassium or sodium cyanide, and electrolysis from the cyanide solution.

The corrosion resistance of cadmium is good in rural atmospheres but not in industrial neighborhoods, where sulfur dioxide or trioxide is present. Unsaturated oils attack cadmium owing to their acid constituents. Hydrogen sulfide in concentrations present in industrial atmospheres does not harm cadmium.

Metals that are appreciably soluble in cadmium include gold, silver, cobalt, copper, magnesium, nickel, lead, platinum, antimony, tin, and zinc. Columbium, chromium, tungsten, and molybdenum are somewhat resistant to attack by cadmium.

## TOXIC

Cadmium is poisonous. Johnstone (*54*) discusses the toxicology of cadmium at length; his opening paragraph is decidedly pertinent:

> Cadmium has probably more lethal potentialities than any other of the metals. Lead, mercury, manganese, and many others may bring about an acute or chronic illness, but rarely do any of these cause sudden death from an acute exposure. Failure to appreciate the toxic properties of this metal (cadmium) has caused workers to be unwittingly exposed to its fume and has furthermore allowed manufacturers to incorporate this metal in products without due warning of its presence.

Industrial processes in which cadmium poisoning may occur include the smelting of cadmium-bearing ores, working up of residues, welding of alloys, spraying of cadmium-bearing paints and pigments, manufacture of cadmium compounds, melting the metal, and cadmium plating.

The following occupations have been listed as offering exposure to cadmium: Cadmium-alloy makers, cadmium and cadmium-compound makers, cadmium platers, cadmium-vapor-lamp makers, calico printers, chargers (zinc smelting), color makers, electroplaters, glass colorers, lithopone makers, solderers, solder makers, storage-battery makers, welders, zinc smelters and refiners, chemical process men, glassblowers, cupola tenders, painters, polishers, grinders, and buffers.

The toxicity of cadmium is described in some detail in the following section, which was prepared for this report by Frank Princi, M. D., University of Cincinnati, Department of Preventive Medicine and Industrial Health, College of Medicine.

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The maximum permissible concentration of cadmium allowable per day by ingestion has been set at 1 mm. per kg. Toxic symptoms produced by ingestion of the metal are vomiting, diarrhea, salivation, anorexia, weakness, and loss of weight. Most of the cases of toxicity resulting from cadmium ingestion have been accidental in nature; however, it should be remembered that cooking and eating utensils should not be plated with cadmium, since the cadmium can be dissolved in acids and may cause gastric disturbance.

The main route of cadmium absorption during industrial exposure is by inhalation. The recommended maximum allowable concentration for cadmium in air has been set at 0.1 *milligram* per m.$^3$ of air by the American Standards Association. This M. A. C. can be considered to have validity with reference to cadmium fumes only. Acute inhalation exposures are followed by a latent period from 4–36 hours. During the first several hours there are no noticeable symptoms except for possibly mild irritation of the eyes, dryness of the throat, and a tightness in the chest. These symptoms progress to coughing, shortness of breath, chest pain, cyanosis, and occasionally gastrointestinal symptoms. The signs and symptoms of a generalized pneumonia may ensue. This syndrome is typical of chemical pneumonitis and is not peculiar to cadmium alone.

In workers exposed to lower concentrations of cadmium fumes and dusts over a long period of time, a syndrome manifested clinically by a yellowish pigmentation of the teeth, vague motor disturbances, pain in the lower legs, and finally by difficulty in walking has been described in Europe. It has not been observed clinically in the United States.

A thorough description of the experimental pathological effects of cadmium has been given by Prodan. He administered the metal to cats by several different routes. By ingestion, the liver and kidneys were affected, but all the doses were large enough to produce acute manifestation of poisoning. By inhalation, cadmium sulfide produced a bronchopneumonia accompanied by edema and extensive emphysema and sometimes pleural effusion. Studies by Princi et al. showed that dogs tolerated without difficulty the inhalation of an average concentration of 4 mg. of cadmium oxide and cadmium sulfide dusts. As with all industrial exposures, the various compounds of the same element and the various physical forms of the same compounds may result in great differences in physiologic effect. These differences are most apparent in industrial exposures to cadmium where fumes provide the most serious hazard.

As with other toxic substances, prevention of undue exposure remains the best treatment. All industrial processes where cadmium fumes are developed should be well ventilated and exhausted. Respirators should be employed for unavoidable exposures to extremely high concentrations. Acute inhalation exposure should be treated immediately with oxygen therapy, even though the patient may appear only moderately overcome by the fumes. Appropriate chemotherapy can be instituted if a secondary pneumonia is suspected.

Death due to cadmium by ingestion is rare for it acts as a violent emetic and usually not enough of the metal is absorbed to cause serious damage.

BAL (2,3 dimercaptopropanol) has been used with success for the treatment of cadmium poisoning incurred both by inhalation and ingestion.

# USES

The chief uses of cadmium in 1955 were as a protective coating, usually applied by electroplating, and in chemical compounds; about 88 percent of available cadmium was consumed for these purposes. For the period 1940–44, 71 percent of the cadmium consumption of the United States was in electroplating, 11 percent in bearing alloys, and the remainder in pigments, solders, miscellaneous alloys, and various chemicals. (See table 2.) Since World War II cadmium has also been used in small quantities in nickel-cadmium batteries and in the atomic energy program.

## METAL

Cadmium metal is used chiefly as a protective covering on other metals, competing with zinc as a protective coat on ferrous metals. About 58 percent of the cadmium consumed in 1955 went for that use. The metal is also employed in the production of bearings, solders, and other alloys. The production of alloys utilized 9 percent of the cadmium consumed in 1955. At present there are no statistics on the use of cadmium metal in the control of nuclear reactors, but its high ther-

TABLE 2.—*Consumption of cadmium in the United States, by uses, 1940–44 and 1955*

(Thousand pounds)

| | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 |
|---|---|---|---|---|---|---|
| Electroplating | 3, 692 | 4, 586 | 6, 661 | 6, 481 | 5, 496 | 4, 705 |
| Bearings | 1, 300 | 1, 504 | 282 | 249 | 798 | 5 |
| Solders | 73 | 130 | 201 | 285 | 266 | 10 |
| Other alloys | 281 | 221 | 98 | 198 | 89 | 740 |
| Pigments | 783 | 1, 246 | 367 | 139 | 177 | 2, 709 |
| Chemicals | 49 | 79 | 50 | 29 | 89 | |
| Others | | | | | [1] 1, 950 | |
| Total | 6, 178 | 7, 766 | 7, 659 | 7, 381 | 8, 865 | [2] 8, 169 |

[1] Includes cadmium for unspecified uses.

[2] Consumption based on an 88-percent reply to survey. Includes 522,814 pounds of cadmium oxide (cadmium content), of which 167,371 pounds was used for electroplating and other metal alloys, 182,609 and 172,834 pounds for pigments and chemicals and other uses, respectively. Similar information not available for other years.

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mal neutron cross section (2,400±200 barns) indicates it is a metal of interest in this field of use.

## PROTECTIVE COATINGS

Cadmium metal is widely used as a protective coating for iron and steel and, to a much smaller extent, on other metals. Electrodeposition of cadmium is the only commercial method used for applying it as a protective coating; however, the metal may be directly applied by spraying or hot dipping.

### ELECTROPLATING

In the electrodeposition process cadmium compounds in solution are electrically decomposed, and cadmium metal is deposited on the object to be coated.

**Procedure.**—Although cadmium can be deposited from acid baths, such as sulfate or fluoborate, virtually all commercial plating is from cyanide baths. Acid baths do not give good deposits without effective addition agents and also have poor throwing power. The prime value of cadmium sulfate solutions in electroplating is to provide very thin but highly adherent undercoatings for heavy coatings from cyanide cadmium baths. As the deposits usually are very crystalline and show a strong tendency toward treeing, highly colloidal addition agents (such as gelatin) must be used. These are too unstable in the bath, even in the presence of protective colloids, to give commercially satisfactory plating results.

Almost every bath characteristic of consequence favors the cyanide cadmium bath—its ability to give a dense, fine-grained deposit that may be made highly lustrous and reflective by the use of agents that are stable in the bath; high and easily balanced anode and cathode efficiencies; excellent covering power; and good plate distribution on recessed articles. Consequently, the cyanide bath is used almost exclusively for commercial cadmium plating.

Modern commercial cadmium electroplating baths consist essentially of sodium cadmicyanide, sodium cyanide, sodium hydroxide plus organic, and sometimes inorganic addition agents and brighteners. They usually are made by dissolving cadmium oxide in sodium cyanide solutions to give a bath with the sodium hydroxide content equivalent to the cadmium content. The cadmium content usually runs from 1.8 to 4.5 ounces per gallon.

The metallic cadmium content varies with the items to be plated and is one of the factors that determines the maximum permissible current density. The cathode efficiency will vary with the metal content, that is, low metal–low efficiency, high metal–high efficiency. This effect is less marked in cadmium solutions than in other cyanide solutions, such as copper and zinc. The metal content should be maintained by anode corrosion as far as possible.

The sodium cyanide content is important, since it provides conductivity and makes anode corrosion possible in the use of soluble cadmium anodes. In some baths the appearance of the plate depends on the ratio of cadmium metal to free cyanide; high cyanide content results in low cathode efficiency, and low content results in a dull deposit at both high and low current densities. The usual sodium cyanide content is 12 to 17 ounces per gallon.

The caustic soda content is not very critical. Except in case of the dragin of pickling acid, it is maintained by the difference in anode and cathode efficiencies. The usual content is from 2 to 4.5 ounces per gallon. Its prime function is to help conductivity. An excess causes the bright plate current density range to narrow.

The organic brighteners used in cyanide cadmium plating solutions include complex, nitrogen-containing condensation products of high molecular weight and certain sulfonic acids. Many other substances used as brighteners have been patented; most of them are effective in baths of relatively low concentration.

As the bath concentration and cathode current density increase, it becomes progressively more difficult to secure smooth, bright deposits by using organic addition agents alone, in which case small amounts of certain metallic salts may be added to obtain optimum results. Nickel and cobalt salts, when used in conjunction with suitable organic addition agents, permit current densities to be employed considerably in excess of those obtainable by using organic addition agents alone. Nickel tends to codeposit with cadmium to a very slight extent when the bath composition becomes low in cadmium or sodium hydroxide. Cobalt is equally as effective as nickel but is required in larger amounts and does not codeposit with cadmium under conditions observed in normal bath operation.

The commonest sources of impurities in plating baths are dirty tanks, drippage, splashing, fumes, dragin, incorrect additions, and dissolving of the parts to be plated. Cadmium baths are particularly susceptible to metallic impurities. Copper is the commonest metallic contaminant and causes a film when low current density is used. Zinc causes cloudiness in high concentrations. Small amounts of nickel increase the luster of the plate, but larger amounts cause streaks and decrease the efficiency of the bath. Antimony, tin, silver, arsenic, and lead destroy the luster of the plate, while hexavalent

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chromium, such as is found in chromic acid and many chromate treatments used on cadmium and zinc deposits, causes blistering and little or no depositing takes place below 25 amp. per sq. ft.

Metallic impurities may be decreased by treating the solution with cadmium sponge or zinc dust to bring about precipitation or by electrodeposition at a low current density. Chromic acid passivates steel and thereby delays coverage. It may cause blistering and causes severe anode polarization and loss in anode efficiency. It may be removed by sodium hydrosulfite.

Nitric acid has no effect on the appearance of the plate but cuts down cathode efficiency. Chloride and sulfate ions have no direct effect on the appearance of plate but tend to make iron anodically soluble. Oil and grease produce blotchy white deposits; they may be removed by using activated carbon and a filter aid. This process removes the brightener, which must be replaced. The presence of carbonate results from the breakdown of sodium cyanide. Concentration of the carbonate is accelerated by excessive bath temperatures and also by absorption of carbon dioxide from the air. It results in a decrease of free cyanide, anode polarization, and increases in tank voltage. The current density drops, plating time increases, and the appearance of the plate changes to frosty white, then gray. Small amounts are not objectionable but should not exceed 6 ounces per gallon in a 5-ounce-per-gallon cadmium solution or 11 ounces per gallon in a 2.5-ounce-per-gallon cadmium solution. It is prevented mainly by preventing high temperature; it may also be decreased by dilution of the solution and by limiting exposure of the solution to air. Sodium carbonate may be removed from the solution by precipitation reagents or by freezing out. Constant filtration in electroplating is desirable to prevent accumulation of suspended matter, which may cause rough deposits. However, cadmium baths are not as susceptible to rough deposits as are other baths. In modern practice filtration is used seldom and in some instances not at all.

The standard plating cycle consists of use of an alkaline cleaner, a warm rinse, a cold rinse, an acid pickle, a cold rinse, cadmium plate, a cold rinse, a hot rinse, and drying.

Electroplating usually is conducted at room temperature or between 75° and 100° F. for uniform results. Considerable variation can sometimes be tolerated if a change in the bath composition compensates.

For best results the current density range widens and moves toward higher current densities as the cadmium content increases. The cadmium content depends largely on the relative value of the investment in tank, solution, and floor space. Barrel plating solutions usually are operated with a rather low cadmium content, because of the agitation employed, while still tanks and automatic solution are operated with higher cadmium content.

The average effective current density is 15 to 20 amp. per sq. ft. in solutions containing 2.5 ounces per gallon of cadmium and 30 to 40 amp. per sq. ft. in solutions containing 5 ounces per gallon of cadmium. Anode current density in commercial conditions usually should not exceed 20 amp. per sq. ft. Cathode current efficiency varies with the bath composition—between 85 and 98 percent. The efficiency increases with increased metal content; increased cyanide and brightener decrease the efficiency, while caustic soda increases it. Small quantities of carbonate have no appreciable effect.

In plating from cadmium cyanide solutions soluble cadmium anodes generally are used. Auxiliary insoluble steel anodes sometimes are employed in special instances. Additions of cadmium salts are required to keep up the metal content when soluble anodes are used. The cadmium anodes are usually chill-cast and must meet the following specifications: Minimum cadmium, 99.9 percent; silver plus lead plus tin maximum, 0.05 percent; arsenic plus antimony plus thallium maximum, 0.005 percent. Anodes from bearing scrap generally contain too much silver and tin and sometimes too much nickel and lead. The impurities go into solution at high anode current densities and cause irregularities at the cathode. They may form sludges at low densities and contaminate the plate.

Cadmium is electroplated on rough or machined basis metal, with no buffing or polishing treatment. Small parts are sometimes ball-burnished. Cleaning in organic solvents before the alkaline cleaning removes heavy oil and grease. Steel parts frequently are precleaned by immersion without current in cleaner of caustic soda and soap. Anodic cleaning is also used. Pickling is done at room temperature in hydrochloric acid; heavy scale is best removed by sulfuric acid. If inhibitors are employed to lessen acid attack on steel, the work should be given a short dip in uninhibited muriatic acid. Scale on copper and red brass is removed in hot dilute sulfuric acid and scale on yellow brass in cold dilute sulfuric acid. The brass and copper are usually then bright-dipped in sulfuric acid–nitric acid–hydrochloric acid.

Cadmium coatings are generally used "as plated." The commonest method of finishing is known as "bright dipping." The known bright dips are acid solutions of considerable oxidizing power. The bright dips may contain single compounds, such as ½ to 1 percent by

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volume of concentrated nitric acid of sp. gr. 1.4 or mixtures of acids with suitable oxidizing agents, such as chromic acid and hydrogen peroxide. By far the largest volume of bright dips being used for cadmium is based on chromic acid.

Cadmium plate is mechanically finished to only a small extent. Such finishing necessitates enough care in preparing the basis metal before finishing so that good adhesion is assured and blistering prevented. Large, cadmium-plated metal parts may be buffed or scratch-brushed with light pressure.

Cadmium plate is sometimes finished by lacquering and/or painting. Many clear lacquers are available that adhere well to cadmium as long as ordinary precautions of cleanliness are taken. Pigmented lacquers and paints frequently do not adhere and require pretreatment of the plate by bonderizing in phosphate solutions or by treatment in cold chromate solutions.

**Advantages and Limitations.**—Cadmium is used as a protective coating in preference to zinc for the following reasons: (1) Thinner coatings provide equal protection on some applications; (2) the rate of deposition for a given amperage of electric current is larger, hence electricity power costs are reduced; (3) electrical resistance of plated contacts is lower; (4) cadmium retains its metallic luster longer; (5) plated parts are more easily soldered; (6) cadmium has a greater resistance to alkali and salt-water corrosion; (7) it is superior in throwing power, or ability to deposit uniformly on intricately shaped objects; and (8) corrosion by galvanic action is more effectively minimized.

Another advantage of electrodeposited cadmium is its high ductility. Parts to be formed or stamped may be plated before these operations, as the ductility of the deposits permits the cadmium to spread over the areas of bending. Still another advantage of cadmium over zinc is that the cathode efficiency of cadmium is considerably higher than that of zinc, and therefore less difficulty is experienced with hydrogen embrittlement during plating on high-carbon steel. Zinc plate on alloy steel at elevated temperatures causes intercrystalline corrosion and fatigue failure; this is not true of cadmium plate. The chief disadvantage of cadmium plating is its higher cost compared with zinc plating.

Cadmium plating is silver-white and has a good luster; these characteristics make it useful where appearance is important. Cadmium is easy to plate, since control of the bath is less critical than for other metals, the solutions are easier to analyze and control, and the process requires less equipment and floor space. It covers malleable and cast iron, as well as some high-carbon steels, and calls for less care in removing grease and oxides. Some such articles are almost impossible to plate in a cyanide zinc solution whereas cadmium covers them quite easily.

Zinc coatings are equal or slightly superior to cadmium coatings of the same thickness in industrial, suburban, rural, and sea-coast atmospheres. Cadmium is superior to zinc when subjected to extended salt spray or submersion in salty water. In salt-spray tests, zinc specimens quickly become discolored and show a steady loss in weight, whereas cadmium maintains its silver appearance much longer and, after an initial weight loss, begins to take on weight, suggestive of formation of a protective oxide coating. However, resistance to salt spray as a standard test is not indicative of cadmium's resistance to atmospheric corrosion. Cadmium chloride formed with salt spray is less soluble than zinc chloride, which would seem to indicate the reason for the superiority of cadmium under these conditions, but cadmium does not do as well in actual use as the salt-spray tests indicate, showing that other compounds must be formed that are soluble. Cadmium shows low resistance in industrial atmospheres where sulfates are among the corrosion products owing to the high solubility of cadmium sulfate. The corrosion products of cadmium do not accumulate like those of zinc, and cadmium plating may therefore be used in corrosive atmospheres where such accumulations would be harmful, as by interfering with the smooth working of machines.

**Applications.**—The corrosion resistance of cadmium is due to (1) the formation of protective oxide or chloride coatings and (2) electrochemical protection of exposed basis metal. Its relatively high price usually limits its application to parts used indoors or in sheltered places outdoors, where thin coatings will give adequate protection, although aircraft, marine, and military uses are common. The most common uses of cadmium plating are casket hardware, automotive nuts, bolts, screws, springs, fasteners and washers, nails, rivets, carburetor and magneto parts, builders' hardware, aircraft parts, radio and television parts, chassis and marine hardware, malleable fittings, electrical parts, wire screen, tools, stampings, and screw machine parts. The resistance of cadmium plate to chemicals is somewhat low, but it dissolves very slowly in alkalis and is therefore used to protect washing equipment, factory partition legs, steel embedded in concrete, and other articles coming into contact with washing compounds. Since solder adheres readily to cadmium plating, cadmium is used on steel and other metals and is serviceable on electrical contacts. Cadmium plating is used

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where dissimilar parts are in contact, since the plating prevents galvanic currents in moisture that result in corrosion. It is also used to protect brass, since the potential difference between cadmium and brass is less than that between zinc and brass. It is used in the packing industry for articles that come in contact with greases containing oleic and stearic acids; but, owing to its toxic properties, it cannot be used for articles that come in contact with food. It is used, in commercial thicknesses, on cheap ball bearings, worn gears, and ball points.

Cadmium is somewhat soluble in brass (especially high-zinc brass) at room temperature. Copper and cadmium alloy only at high temperatures. Brass coatings less than 0.00005 inch thick absorb in a few months; however, the alloying does not continue indefinitely and seems to reach a saturation point. Alloying increases in extent and speed with increase in temperature. For the same protection, thicker cadmium plating should be put on copper and its alloys than on iron and steel; all copper-base alloys need about the same thickness of cadmium. Copper and its alloys accelerate the corrosion of iron and steel in electrical contact. Plating only the steel part still results in acceleration of the corrosion by copper. Clean copper is the best electrical conductor, but its resistance rises with oxidation under heat and pressure; the resistance of cadmium rises much less. Zinc is not a satisfactory substitute for cadmium where electrical grounding is involved, since the electrical resistance of zinc-plated surfaces is higher. Cadmium-plating solutions containing mercury cannot be used on brass, since the mercury diffuses into the brass and causes season cracking.

Cadmium is not a suitable undercoating for thin silver coatings, despite the similarity of color. The cadmium absorbs the silver, leaving a dark surface. Nickel and copper are better undercoats.

Both cadmium and zinc are electronegative to iron and therefore protect by preferential corrosion. Because zinc is more electronegative than cadmium, zinc will protect iron over a greater environmental range than cadmium. However, this same property of zinc will cause it to dissolve more rapidly, leaving the iron bars subject to direct attack. Cadmium, used in 0.0001-inch thickness to protect piano wire, does not impair the tone.

The disintegration of cadmium coatings in tropical climates to form a white, nonadherent powder is known as "white-powder corrosion". Bakelite and Bakelite-impregnated materials do not attack cadmium but do attack zinc. Zinc is attacked more readily by corrosive materials than is cadmium.

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### OTHER APPLICATION METHODS

Direct application of cadmium metal as a protective coating on other metals is accomplished by hot dipping or spraying while in molten condition (*91*). In the hot-dipping process the metal object to be coated is dipped bodily into a bath of molten cadmium for a short time.

In the metal-spraying process cadmium is melted in a gas-heated graphite crucible. The molten metal is gravity-fed to a spraying nozzle, from which it is ejected by a stream of preheated, compressed air onto the surface to be coated.

## NICKEL-CADMIUM BATTERIES

Although well known in Europe for many years, nickel-cadmium batteries have come into use in this country only since World War II. This battery was invented in Sweden by Waldemar Jungner and Karl Berg around 1900; in 1909 a Swedish company began commercial production. Within 10 years 4 firms in Sweden, England, France, and Germany were making nickel-cadmium batteries under various licensing agreements.

Bus fleets and railroads reported that batteries used 10 and 15 years were in excellent condition. A cadmium battery installed in a diesel rail car in Sweden in 1913 was in use in 1948 after starting the engine 300,000 times. The battery found wide use in motorcycles because it stood up under heavy vibrations. Many business and professional men and automobile fanciers have installed it in their cars, although the price has been 2 to 3 times greater than for a comparable lead battery.

Advantages of the nickel-cadmium battery include (1) its long life (*55*)—over 3,000 cycles of charge and discharge (*88*); (2) the fact that it cannot be damaged by overcharging, reverse charging, or short circuits; (3) simple maintenance; (4) delivery of maximum current with minimum voltage drop; (5) high discharge rate without damage to cells; (6) quick charging; and (7) wide range of operating temperature—from −65° to 165° F.

Nickel-cadmium batteries are used at present principally for heavy-duty wear, such as in buses, diesel locomotives, and other heavy machinery; however, the battery can be employed for almost any purpose where use of a storage battery is indicated.

Nickel-cadmium batteries are alkaline-type storage batteries. Several types have been developed. In one type the active material of the positive plate consists of nickel hydroxide and graphite; the negative plate consists of a mixture of cadmium and iron oxides. The electrolyte is a solution of potassium hydroxide in dis-

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tilled water. Nickel hydroxide, $Ni(OH)_3$ is a very poor electrical conductor, and the graphite (approximately 25 percent) is required to raise the conductivity. When charged, the cadmium oxide is reduced to finely divided metallic cadmium, and ferric oxide is required to prevent a tendency to coagulate. The following equations may be assumed to represent the chemical reactions taking place in the cell:

*Positive*

$$\text{Charge—}2Ni(OH)_2+2OH \rightarrow 2Ni(OH)_3.$$

*Negative*

$$CdO+H_2O+2K \rightarrow Cd+2KOH.$$

*Positive*

$$\text{Discharge—}2Ni(OH)_3+2K \rightarrow 2Ni(OH)_2+2KOH.$$

*Negative*

$$Cd+2OH \rightarrow CdO+H_2O,$$

or

$$NiO+CdO \rightarrow NiO_2+Cd.$$

Characteristics of the cell include the following: (1) The chemical reactions are perfectly reversible; (2) the active materials cannot react with the electrolyte when the battery is on open circuit; (3) the specific gravity of the electrolyte does not change during the complete cycle; and (4) the cell does not gas when charged properly or when discharged. If the oxides and hydroxides of nickel and cadmium were completely pure, the cell would have no self-discharge but would also be very high priced. Therefore, a certain amount of impurity is tolerated that still allows a long-life battery. However, if the cell becomes dirty or is stored in a humid place, considerable external self-discharge can take place. The length of life of the battery seems to depend on the rate of solubility of the graphite in the electrolyte. The quantity of electrolyte may be reduced to a minimum, and the plates may be very close together and thin, reducing internal resistance. The specific gravity (18° C.) of the electrolyte is approximately 1.29. Potassium hydroxide will absorb carbon dioxide from the air to form the carbonate, which increases the internal resistance but does not decrease its ability to furnish heavy discharge currents for engine starting or switch closing. The average voltage obtained is 1.2 volts per cell.

The positive and negative plates are of the same design and appearance. The active materials are manufactured in powdered form and forced, under high pressure, into flat tubes or "pockets" made of very finely perforated nickel-plated steel strips, which are seamed along their edges. The pockets are mounted horizontally under great pressure in plate frames of nickel-plated steel. The plates are separated mechanically and insulated from each other by polystyrene rods and from the cell jar by hard rubber. The finished product is encased in a steel container, making it very resistant to damage. These individual cells (the number is governed by the size and voltage needed) are arranged in hardwood trays.

Another nickel-cadmium battery of the sintered-plate type, using potassium hydroxide as the electrolyte, has been developed recently and put on the market. In this battery the grids of both positive and negative plates consist of sintered carbonyl nickel powder. The active material of the positive plate, when charged, is nickel oxide, and that of the negative plate is cadmium. Cadmium is impregnated on the plates as cadmium nitrate, electrolyzed to cadmium hydroxide, and then to cadmium oxide, which during charge gradually loses oxygen and becomes metallic cadmium. The nickel oxide (active material of the positive plates) is brought to a higher state of oxidization. These charges in both sets of plates continue as long as the charging current is applied or until the active materials of the plates have been completely converted.

During discharge a reverse chemical action occurs. The positive plates gradually return to a state of lower oxidation, and the negative plates gain back oxygen. During this process the chemical energy of the plates is converted into electrical energy, which is released as current flows through the load. Each plate of the cell-core assembly has, as its foundation, a screen of nickel-wire mesh. This screen is converted into a sheet as nickel powder is deposited in its meshes by a sintering process. It is the active material electrochemically deposited within the pores of the sheets that distinguishes between negative and positive plates.

Each cell consists of a transparent plastic case, housing a core assembly of positive and negative plates and a separator of multiply fabric and plastic sheet interwound among the plates. The battery of cells is housed in a steel battery case. The ratio of cadmium to nickel in the battery is about 1:9.5. In the 6-volt, 30-amp.-hr. battery there is less than 2 pounds of cadmium.

## ATOMIC ENERGY

In addition to its major uses, cadmium occupies an important place in nuclear physics, where it is employed to control the fissioning process in reactors. Its specific use in nuclear physics was disclosed under terms of an agreement among the United States, Canada, and the United Kingdom to make public scientific discoveries that have no military value (*75*).

It was revealed that the fission rate of a nu-

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clear reactor is controlled by cadmium rods projecting into the region of fission. Cadmium absorbs thermal neutrons readily, so that not enough neutrons remain free to start an uncontrolled chain reaction of splitting. The purpose of a nuclear reactor is to produce neutrons and heat, and pulling the cadmium rods out starts production. Adjustment of the cadmium rods determines the rate of fission and quantity of heat produced by the reactor.

## ALLOYS

An important use of cadmium metal is in alloys. The most important cadmium-base alloys and alloys containing cadmium are used in bearings, solder, low-melting-point alloys, telegraphic, telephonic, and power-transmission lines, and silver brazing.

Data on the binary, ternary, and quaternary alloy systems of cadmium are discussed by Budgen (*3*) and McCutcheon and Musgrave (*78*).

### BEARING METALS

The efficiency with which a machine operates depends to a large extent upon the loss in power experienced by the moving parts in contact with each other and in contact with their supporting bearings. The basic function of the bearing alloy is to maintain a low coefficient of friction between the bearing and the moving part. A bearing is usually made softer than the moving part it supports, yet strong enough to carry the load (*51*).

The main requirements of a good bearing metal are: (1) Mechanical strength, hardness, tensile strength, and compressive strength; (2) bonding characteristics—adherence to the steel or bronze back (all bearings are not bonded); (3) relatively high melting point; (4) fatigue resistance; (5) antifriction characteristics; (6) nonscoring characteristics; (7) conformability; (8) embeddability—ability to absorb particles rather than having them interfere with the movement; (9) thermal conductivity; and (10) corrosion resistance.

Cadmium-base bearing alloys that contain at least 97 percent cadmium have low frictional properties, high strength, and toughness at elevated temperatures, high melting points, temperature stability, and a wide range of hardness. These alloys have a much greater fatigue life than the lead-base or tin-base alloys. In casting and bonding them to steel backs, a stronger and more permanent bond may be obtained by first coating the steel with a cadmium-nickel alloy. Cadmium-base bearing alloys have enough conformability to withstand shaft deflections without scoring or seizure and are tough enough to prevent cracking at the edges. Cadmium-base bearing metals are used chiefly in internal-combustion engines for service under high pressures and temperatures and at high speeds.

The cadmium-base bearing alloys most commonly used are the types containing approximately 1.3 percent nickel and 98.7 percent cadmium (Asarcoloy) and the cadmium-silver-copper alloys containing 0.5 to 2.25 percent silver, 0.25 to 0.50 percent copper, and the remainder cadmium. The cadmium-nickel alloy probably is preferable. The cadmium-copper-magnesium alloys used at one time suffer from intercrystalline corrosion and are now out of use.

Cadmium-base bearings formerly were used much more commonly than at present; during World War II this was the second largest use of cadmium, exceeding 1 million pounds annually for several years. Currently, the use of cadmium in bearings is relatively small.

The cadmium-nickel alloy is the only white metal used for bearings for linings in heavy-duty, sliding-type bearings. These alloys are characterized by high melting temperature and high fatigue resistance.

"Graphalloy," a cadmium - impregnated graphite containing 30 to 35 percent cadmium, is used in oilless bearings, bushing linings, and for electrical purposes, chiefly brushes and contacts for controller switches.

Silver dissolves in up to 2.5 percent cadmium; copper is slightly soluble, the eutectic being 98.9 percent cadmium. A hard solution is attained more cheaply in using copper, but copper hardens and strengthens cadmium at the expense of ductility and toughness. The addition of silver gives a better combination of strength, hardness, and ductility. The cadmium-silver-copper alloys have a melting range of 600° to 620° F. and can be used at much higher temperatures than other white metals. Impurities leading to low-melting eutectics must be avoided in bearing metals. These alloys can be deposited electrolytically. They are used only in steel-backed bearings, where their bond strength is better than that of the tin- or lead-base alloys.

Babbitt-metal bearings (tin-base-alloy series containing antimony and copper) may contain 1 percent cadmium to increase strength and antifriction properties.

The chief disadvantage of cadmium-base alloys is their susceptibility to corrosion by lubricants that contain organic acids. Plating the bearing with indium helps this condition appreciably, but indium is extremely expensive. However, such small quantities are necessary to give protection that the cost is not entirely prohibitive.

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## SOLDERS AND SILVER BRAZING ALLOYS

Cadmium can be substituted for tin in rather large proportions in solders. Solders containing some tin are better than those that are completely tin free. Replacement of tin results in some loss in joint strength and working qualities; and, owing to the tendency of cadmium oxide to become entrapped in the joints, decreased mechanical strength and an increase in porosity are apt to occur. In tin-free lead-cadmium solders the melting point is higher than in the tin-lead-cadmium alloys, and care must be taken to avoid oxidation. The capillary action of these solders is advantageous in some fields.

The cadmium-zinc soldering alloys make joints of acceptable strength and are not oxidized as easily as the lead-cadmium alloys. They are characterized by high shear strength.

Typical cadmium solders have the following compositions: (1) 22.5 percent cadmium, 71 percent zinc, 5 percent tin, and 1.5 percent copper; (2) 9 percent tin, 65 percent lead, and 26 percent cadmium; (3) 3 percent tin, 75 percent lead, and 22 percent cadmium; (4) 68 percent lead, 23 percent tin, and 9 percent cadmium (a satisfactory wiping solder); and (5) 40 percent cadmium, 60 percent zinc. The first alloy listed above (containing 22.5 percent cadmium) is particularly useful with flexible metal tubing. Approximately half of the tin in tin-lead solders can be safely replaced with cadmium but with the disadvantage mentioned previously.

The principal uses of cadmium-silver alloys are in solders and bearing metal. The cadmium functions as a deoxidizer. About 0.5 percent is added to sterling silver to reduce the copper oxide for sounder casting and whiter sterling.

The characteristics of the silver brazing alloys make it possible to join both ferrous and nonferrous metals with strong, ductile, leaktight, corrosion-resistant joints. The corrosion resistance of the alloys is due mainly to the silver content. The relatively low temperature at which these alloys melt makes them very useful on copper. An alloy containing 35 percent silver, 26 percent copper, 21 percent zinc, and 18 percent cadmium, which has a melting point of 1,125° F. and a flow point of 1,295° F., is a good general-purpose brazing alloy. Its lower melting and flowing points make it more useful with lower melting temperature base metals. "Easy-Flo," manufactured by Handy & Harman, has a basic composition of 50 percent silver, 15.5 percent copper, 16.5 percent zinc, and 18 percent cadmium; its melting point is 1,160° F. and flow point 1,175° F. Its electrical conductivity is 23.9 percent that of pure copper. A similar alloy contains 45 percent silver, 15 percent copper, 16 percent zinc, and 24 percent cadmium. Both these alloys have low flow points and good strength characteristics, making them useful in joining such metals as carbon steel, stainless steel, nickel and nickel alloys, and copper and copper-base alloys. An alloy containing 50 percent silver, 15.5 percent copper, 15.5 percent zinc, 16 percent cadmium, and 3 percent nickel (melting point, 1,195° F.; flow point, 1,270° F.) is used in brazing tungsten carbide to other metals and is an excellent alloy for brazing tungsten and molybdenum.

Brazing alloys containing 35 to 48 percent silver, 10 to 15 percent copper, 12 to 17 percent zinc, 12 to 20 percent cadmium, and 2.5 to 20 percent indium and alloys containing 10 to 25 percent silver, 3 to 10 percent copper, 25 to 40 percent zinc, and 30 to 50 percent cadmium, for use in brazing, welding, and soldering processes, have been patented (*56*, *57*).

## USES BASED ON LOW MELTING POINT OF ALLOYS

Low-melting-point alloys containing cadmium are used in fire-detection apparatus, fusible elements in automatic sprinkler heads, fire-door release links, automatic shutoffs for gas and electric water-heating systems, safety plugs for compressed-gas cylinders, tanks, etc., and temperature-controlled safety clutches.

Bronze containing up to 1 percent cadmium has moderately high strength, high electrical conductivity, and good abrasion resistance. Larger amounts of cadmium are considered harmful.

The alloy known by the trade name "Cerrobend" is used as a filler in bending thin-walled tubes, which would otherwise crumple in the bending process. Cerrobend contains 50 percent bismuth, 26.7 percent lead, 13.3 percent tin, and 10 percent cadmium and is a eutectic alloy that melts at 70° C. (158° F.). The finished product is put in boiling water to melt the filler, which can be collected and reused. It is also employed as a filler in manufacturing hollow sterling silver, while the metal is shaped between dies. Other uses include anchoring fragile materials in machining, models for engraving machines, certain types of dies, model replicas, gages, assembly fixtures, and plugs for chlorine containers, where ease of molding and corrosion resistance are important. It is also known as Lipowitz alloy.

Accurate proof castings can be made with the alloy trade-named "Cerrosafe." Its property of shrinkage during cooling to room temperature and then expanding slightly on further cooling makes it a good alloy for that use. It is used in proof casting molds, gun chambers, forging dies, etc., in a sprayed coating for wooden patterns and core boxes, where it elimi-

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nates distortion from moisture. Cerrosafe contains 42.5 percent bismuth, 37.7 percent lead, 11.3 percent tin, and 8.5 percent cadmium and has a melting point of 165° to 190° F.

Wood's metal, an alloy containing 50 percent bismuth, 12.5 percent tin, 25 percent lead, and 12.5 percent cadmium and having a melting point of 68° C., is used in seals and gastight joints in glass apparatus because of its low melting point.

### ELECTRICAL CONDUCTORS

Cadmium alloys quite easily with copper, and quantities up to 50 percent are contained in master alloys for addition to copper and bronze. Low-cadmium copper (0.7 to 1 percent cadmium) is very ductile and has found wide use in telegraphic, telephonic, and power transmission wires, since cadmium imparts good tensile strength, hardness, and high annealing temperature and does not seriously impair its conductivity. It is most useful as trolley wire, where its high strength, high conductivity, and resistance to wear have prime importance. Cadmium-copper alloys can be worked both hot and cold.

An alloy of copper-zirconium-cadmium has proved superior in strength and hardness to copper-cadmium alloys and has about as good electrical conductivity.

### OTHER USES

Cadmium forms amalgams with mercury that become crystalline on standing. These amalgams have been used in the past—sometimes combined with other metals—for filling teeth; however, their use has been largely discontinued owing to the tendency of cadmium to dissolve in acids. Cadmium is poisonous when taken internally. Moreover, these fillings cause discoloration of the tooth enamel. Cadmium amalgams usually contain about 25 percent cadmium and may be made more pliable on heating by the addition of tin or bismuth. The addition of 16 percent mercury to cadmium-lead-bismuth-tin eutectic lowers the melting point from 70° to 55° C. This alloy has been used in place of plaster of paris.

Cadmium forms a green, ductile alloy with gold, which is used in manufacturing jewelry. These alloys contain approximately 75 percent gold, 12 to 16 percent silver, 9 percent copper, and 4 to 12 percent cadmium.

## COMPOUNDS

The most important cadmium compounds in industry are the sulfide and sulfoselenide, and their chief use is as paint pigments. These compounds often are extended with barium sulfate, in which case they are known as cadmium lithopones. Cadmium pigments are useful in cases of exposure, such as on automobiles (where heat resistance is essential, since cadmium sulfide is not as easily oxidized as zinc sulfide) and in atmospheres containing hydrogen sulfide, which darkens paints containing lead owing to formation of the black lead sulfide. Cadmium pigments are used where extreme color retention is required. Some of the commoner uses of the pigments are in durable, nonbleeding automobile and machinery enamels and finishes, artificial leather, coated fabrics, plastics, rubber, soaps, glass, paper, printing inks, baking enamels, ceramic glazes, lithographic inks, and artists' oil and water colors. Cadmium sulfide is also used with ultramarine to produce a green color and as a fluorescent pigment.

The color range of cadmium sulfide is from lemon yellow to orange and of cadmium sulfoselenide from orange and light red to deep maroon. During World War II the phosphorescent qualities of some cadmium pigments were investigated with regard to their use in illuminating certain objects during blackouts. However, their cost was found to be prohibitive for extensive use; and today, the cost factor remains a deterrent to wider use of cadmium pigments.

Descriptions of the more important cadmium compounds follow. Manufacturing processes for cadmium sulfide, lithopone, and sulfoselenide are included because of the importance of these compounds. A table listing the physical properties of the minor compounds may be found on page 25.

### CADMIUM SULFIDE

Cadmium sulfide (CdS), also known as cadmium yellow or jaune brilliant, molecular weight 144.47, occurs naturally as greenockite but has not been discovered in quantities or purity to constitute a commercial source. Cadmium sulfide appears in the amorphous and crystalline forms. The amorphous form may be yellow, orange, or brown. The crystalline form is dimorphous; the alpha form is lemon yellow and has a specific gravity of 3.91 to 4.15, and the beta form is vermilion and has a specific gravity of 4.48 to 4.51. Cadmium sulfide may be prepared by heating cadmium oxide with sulfur but a better quality is obtained by passing hydrogen sulfide through acid solutions of the salts.

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The color of the sulfide precipitated depends upon the particle size, not upon the allotropic modifications. A very hydrous gel of the sulfide is precipitated by hydrogen sulfide or alkali sulfides on a cold solution of a cadmium salt; the color is light yellow when the cadmium sulfide is precipitated from a cold solution of low cadmium content and deep orange when it is precipitated from hot acid solutions with hydrogen sulfide or boiled with excess sodium thiosulfate.

Cadmium sulfide is manufactured in one process by dissolving cadmium oxide in sulfuric acid and precipitating the sulfide from the solution with hydrogen sulfide. Cadmium sulfide may also be made by precipitation from cadmium nitrate with barium sulfide, or by precipitation from a solution of cadmium sulfate with a soluble sulfide such as sodium sulfide.

### SOLAR ENERGY CONVERTER

The United States Air Force recently announced (*87*) development of a solar generator using cadmium sulfide for converting sunlight into electrical energy. Cadmium sulfide powder is processed into crystal form; the Air Force said a wafer-thin 4- by 15-foot slab of the crystal would supply enough current to take care of a house.

The pilot model of the electric generator is said to be about 1 inch square and to supply a charge of ½ volt. Electrodes are attached to opposite sides of the crystal, from which wires run to an electric motor. Sunlight striking the crystal induces a charge in it, and the electric current generated activates the motor.

## CADMIUM LITHOPONE

Cadmium lithopone is prepared by mixing solutions of cadmium sulfate and barium sulfide, which yields cadmium sulfide and barium sulfate. Pure cadmium sulfate is difficult to obtain and is therefore prepared as part of the process by the action of sulfuric acid on the pure cadmium metal. Complete dissolving of the metal in the acid is difficult unless a small amount of nitric acid is added to the sulfuric acid. The nitric acid is reduced in the process, so that no nitrates are formed, or a slight excess is added because of the favorable effect of nitrates in some calcining processes.

An excess of cadmium in the sulfate is desirable to eliminate the necessity of using extra alkalis to raise the pH of the solution. The resultant precipitate of cadmium sulfide or cadmium sulfide and barium sulfate is filtered and calcined in a reducing atmosphere to give it a uniform color. The color of the product depends on the calcining process, the orange shades being obtained when the product is not calcined but simply dried. Lithopones may also be prepared by forming the barium sulfate and cadmium sulfide separately and mixing before calcining.

In some lithopones both cadmium sulfate and zinc sulfate are mixed with barium sulfide to form a cadmium-zinc lithopone. A light yellow may be made by replacing some zinc by cadmium and orange by replacing most of the zinc by cadmium in sulfate solutions. It is often called cadmapone and is used where the air contains hydrogen sulfide gas which prevents the use of other pigments. It is employed in place of regular zinc lithopones for high-temperature use, since cadmium sulfide does not oxidize as readily as zinc sulfide.

## CADMIUM SULFOSELENIDE

These pigments are prepared by adding selenium to a solution of barium sulfide or nitrate, reacting the solution with cadmium sulfate, and calcining with excess sulfur to remove unreacted selenium, which tends to darken and dull the product. It may also be prepared by calcining, under nonoxidizing conditions, a mixture of cadmium oxide, sulfur, selenium, and a cadmium sulfide base. Some recent patents cover the use of processes involving: (1) Decomposition of cadmium selenocyanide in the presence of a cadmium compound and sulfur; (2) calcining a mixture of cadmium sulfide, metallic selenium, and a compound yielding cadmium oxide on heating; (3) calcining compounds capable of yielding sulfides, selenides, or sulfoselenides in an atmosphere of sulfur, selenium, or both; and (4) precipitating cadmium hydroxide from cadmium sulfate solution, reacting it with barium sulfide or a water-soluble sulfide, and calcining the dried basic sulfide with enough sulfur, selenium, or both to replace the oxygen in the basic sulfide.

The above-mentioned processes are simplified versions of a few of the many processes used by companies producing cadmium pigments.

## CADMIUM ACETATE

Cadmium acetate ($Cd(C_2H_3O_2)_2.3H_2O$), molecular weight 284.55, specific gravity 2.01, forms colorless, deliquescent, monoclinic crystals that are soluble in water and alcohol. It is crystallized with some difficulty. It becomes anhydrous when heated to 130° C. and attains a specific gravity of 2.34 and a melting point of 256° C.; the salt decomposes at higher temperatures. Cadmium acetate may be made by dissolving the metal, oxide, hydroxide, or carbonate in acetic acid and evaporating to incipi-

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ent crystallization. It is used in chemical testing for sulfides, selenides, and tellurides and for producing iridescent effects on porcelain and pottery.

## CADMIUM CARBONATE

Cadmium carbonate ($CdCO_3$), molecular weight 172.42, specific gravity 4.26, is a white, crystalline powder, soluble in acids, potassium cyanide, and ammonium salts but insoluble in water. It decomposes below 500° C. The salt can be made by adding an alkali carbonate to a solution of another cadmium salt. It is used principally as a starting compound for manufacturing other cadmium salts.

## CADMIUM CYANIDE

Cadmium cyanide ($Cd(CN)_2$), molecular weight 164.45, is obtained as a white precipitate when potassium or sodium cyanide is added to a fairly concentrated solution of a cadmium salt. It dissolves in an excess of the precipitating reagent owing to formation of the complex ion. The salt is slightly soluble in water and easily soluble in acids, and decomposes when heated above 200° C. in air. The solution of the complex ion is used as an electrolyte for electrodeposition of cadmium.

## CADMIUM HALIDES

The halides of cadmium are very weakly ionized in moderate or strong concentration, a characteristic that may well be due to the tendency of cadmium to form complex ions with halides. Cadmium halides form autocomplexes—salts in which the same metal appears in both the anion and cation—as, for example, $Cd(CdX_4)$. These salts may also contain cations of other metals; these are known as double halides.

*Cadmium chloride*, "butter of cadmium" ($CdCl_2$), molecular weight 183.32, melting point 568° C., boiling point 960° C., specific gravity 4.05, is composed of colorless hexagonal crystals that are soluble in water and methyl and ethyl alcohol. It forms hydrates with 1, 2, 4, and 5 molecules of water. It sublimes at temperatures above red heat, condensing in the form of micaceous plates. The monohydrate forms long needles and the tetrahydrate broad prisms. Cadmium chloride may be made by dissolving the metal in an aqueous solution of hydrochloric acid and evaporating or by dissolving the oxide or carbonate in HCl. When a solution of the chloride is evaporated in air, it leaves a residue of the chloride and the oxide. To prevent formation of the oxide, the solution may be evaporated in a stream of hydrogen chloride gas. The salt is used in photography, in dyeing and calico printing, in testing for pyridine bases, and as a solution for precipitating the sulfides.

*Cadmium bromide* ($CdBr_2$), molecular weight 272.24, specific gravity 5.20, melting point 580° C., boiling point 963° C., is a yellow crystalline powder. The hydrate, containing 4 molecules of water, consists of efflorescent white crystals, molecular weight 344.31. It is soluble in water, hydrochloric acid, and alcohol and slightly so in acetone and ether. The salt may be made by dissolving cadmium metal in bromine water that has been acidified with hydrobromic acid to prevent formation of basic salts, by heating the metal with bromine vapor, or by dissolving in hydrobromic acid and evaporating the solution to dryness. For purification, the residue may be heated to 200° C. and sublimed in a stream of dry carbon dioxide. Cadmium bromide is used in photography, process engraving, and lithography.

*Cadmium iodide* ($CdI_2$), molecular weight 366.25, is a dimorphic material. The alpha form has a melting point of 385° C., boiling point 713° C., specific gravity 5.67; the beta form has a specific gravity of 5.30. It is composed of lustrous white, hexagonal scales that are stable in air. Cadmium iodide is soluble in water, acids, alcohol, ether, and warm ammonium hydroxide and slightly soluble in liquid ammonia and acetone. Cadmium iodide may be made by heating the metal with iodine or by treating a cadmium compound with hydriodic acid. It is used in the form of the cadmium-potassium iodide (known as Marme reagent) as a reagent for morphine, papaverine, and other alkaloids; it is also used in testing ethers for peroxides. It is used for iodizing collodion plates in alcohol and in process engraving and lithography.

## CADMIUM NITRATE

Cadmium nitrate ($Cd(NO_3)_2$), molecular weight 308.49, melting point 59.4° C., specific gravity 2.46, forms white, hygroscopic crystals that are soluble in water, alcohol, and liquid ammonia. It can be made by dissolving cadmium metal, oxide, or carbonate in nitric acid and evaporating to incipient crystallization. The salt is used to impart a reddish-yellow cadmium luster to glass and porcelain ware and as a laboratory reagent.

## CADMIUM OXIDES AND HYDROXIDE

*Cadmium oxide* (CdO), molecular weight 128.41, exists in two forms: Cubic, specific grav-

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ity 8.5, and as a colorless amorphous powder, specific gravity 6.95. The crystals vary in color from light or yellowish brown to dark brown, depending on the method of manufacture. Fine bluish-black crystals may be obtained by condensation from the vapor state. The cubic form volatilizes at 700° C. It is soluble in water and alkalis and soluble in acids and ammonium salts; it reacts with ferric oxide to form a member of the spinel group ($CdFe_2O_4$).

To make cadmium oxide, the pure metal may be distilled in a graphite retort and the vapor permitted to react with air, since the nitride does not form. The oxide thus formed varies in color and must be calcined to get even color. The carbonate or nitrate may be heated to decomposition; the color of the salt resulting from decomposition of the carbonate is lighter than that from the nitrate. The oxide may be reduced by hydrogen or carbon monoxide; cadmium suboxide is thought to be formed as an intermediate product.

Cadmium oxide is used in cadmium plating baths, for sensitizing the photochemical reaction for the formation of hydrogen peroxide from water, and as a catalyst in manufacturing highly unsaturated alcohols by hydrogenation of unsaturated fatty acids or esters. It is an active ingredient of the negative plate of nickel-cadmium batteries. Cadmium oxide, when finely ground with water, molded into shape, and heated to 800° C., forms a mass of high tensile strength, stability, and durability for use as a resistor in electric furnaces. A mixture of 10 percent cadmium oxide or sulfide and 90 percent silver is cold-pressed to form electrical contacts. Cadmium oxide added to titanium oxide and calcined forms a nonchalking pigment. The oxide is also used as a coating for luminescent colors, such as cadmium or zinc sulfide.

*Cadmium suboxide* ($Cd_2O$), molecular weight 240.82, specific gravity 8.192, is a green, amorphous substance that decomposes on heating. It may be prepared in the laboratory by heating cadmium oxalate in a stream of carbon dioxide or by heating cadmium oxide in carbon monoxide. It is also the result of dehydration of cadmium hydroxide formed by the action of water on cadmous chloride, $Cd_2Cl_2$. Cadmium suboxide is formed naturally by the action of air on cadmium plating and forms a protective coating similar to aluminum.

*Cadmium hydroxide* ($Cd(OH)_2$), molecular weight 146.43, specific gravity 4.79, decomposes at 300° C. and is a white powder that is soluble in acids and ammonium salts but insoluble in water and alkalis. It absorbs carbon dioxide to form the carbonate. The addition of ammonium hydroxide to a solution of a cadmium salt produces a gelatinous precipitate of varying composition that dissolves in an excess of the hydroxide owing to formation of the ammonia complex ion. The addition of alkali metal hydroxides yields a voluminous, highly hydrated precipitate that is insoluble in excess hydroxide. The purest cadmium hydroxide may be formed by precipitation from a solution of the nitrate, since less nitrate ion is absorbed in the precipitate than in the chloride or sulfate. Cadmium hydroxide is more soluble than zinc hydroxide and much more basic.

It is used in preparing negative electrodes in cadmium-nickel storage batteries. Cadmium hydroxide made by the anodic oxidation of cadmium (in an electrolyte composed of a 21-percent aqueous solution of potassium hydroxide with a cadmium anode and iron cathode) is used in preparing negative electrodes in cadmium-nickel storage batteries.

## CADMIUM SALICYLATE

Cadmium salicylate ($Cd(C_7H_5O_2)_2.H_2O$), molecular weight 404.65, has a white needlelike structure and is soluble in hot water, acids, ammonium hydroxide, alcohol, ether, or glycerol. It is prepared from salicylic acid and the oxide or carbonate and used as an external antiseptic.

## CADMIUM SULFATES

A table of the specific gravities and melting points of the various hydrated forms of cadmium sulfate is given below:

| | *Specific gravity* | *Melting point, ° C.* |
|---|---|---|
| $CdSO_4$ | 4.69 | 1,000 |
| $CdSO_4.H_2O$ | 3.79 | 108 |
| $3CdSO_4.8H_2O$ | 3.09 | 41.5 |
| $CdSO_4.4H_2O$ | 3.05 | ------ |
| $CdSO_4.7H_2O$ | 2.48 | 4 |

The temperature of the solution in which the hydrated cadmium sulfate crystal forms determines the water of crystallization of the compound. The anhydrous form (molecular weight, 208.47) is composed of white rhombic crystals; the octahydrated form (molecular weight, 769.54) is composed of white, efflorescent, monoclinic crystals. The anhydrous form is soluble in water and insoluble in alcohol, but the octahydrated form is soluble in both alcohol and water. Cadmium sulfate is made by dissolving the metal, oxide, or carbonate in sulfuric acid. The anhydrous sulfate may be prepared by melting cadmium with ammonium or potassium persulfate.

Cadmium sulfate is used for fluorescent screen study of spectral distribution of light emitted by fluoroscopic and intensifying screens excited by X-rays and in medicine for treating such eye diseases as corneal opacities, chronic conjunctivitis, and leucoma. It is an

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antiseptic and astringent and is also used to determine hydrogen sulfide and to detect fumaric acid. A solution of the sulfate in contact with crystals of $3CdSO_4.8H_2O$ is used as an electrolyte in Weston and other standard cells.

## STANDARD CELLS

The Weston standard cell has a positive element of mercury, a depolarizer of mercurous sulfate, a negative element of cadmium amalgam, and an electrolyte of cadmium sulfate solution. In the Weston normal standard cell the electrolyte solution is saturated; however, except for extremely precise work, the unsaturated cell is adequate. Normal cells adjust very slowly to temperature change and are therefore inconvenient for general laboratory work.

The normal or saturated cadmium standard, also called the normal Weston cell, is the one on which the National Bureau of Standards has based its standard for the volt since 1911. It has an electromotive force of 1.01830 international volts at 20° C.

The container of the normal cell is usually an H-shaped glass tube system with sealed-in platinum wires at the lower ends of the vertical legs for electrical connection. In one leg there is mercury and in the other cadmium amalgam. The mercury electrode is covered with a mixture of mercurous sulfate and finely ground cadmium sulfate. A layer of cadmium sulfate crystals is placed upon the surface of both the amalgam and mercurous sulfate. The cell is filled above its crossarm with a saturated solution of cadmium sulfate. These cells are sold in groups, since the voltage delivered is too low for them to be of value separately.

TABLE 3.—*Physical properties of minor cadmium compounds* [1]

| Cadmium compound | Formula | Molecular weight | Crystalline form | Specific gravity | Melting point, ° C. |
|---|---|---|---|---|---|
| Amide | $Cd(NH_2)_2$ | 144. 46 | | 3. 05 | D. 120 |
| Ammonium chloride | $CdCl_2.4NH_4Cl$ | 397. 31 | Rhombic | 2. 01 | Tr. −20 |
| Arsenate | $CdHAsO_4.H_2O$ | 270. 34 | | 4. 164 | 120 |
| Arsenide | $Cd_3As_2$ | 487. 05 | Dark gray cubic | 6. 211 | 721 |
| Borotungstate | $Cd_2B_2W_6O_{32}.18H_2O$ | 2, 738. 03 | Yellow triclinic | | 75 |
| Bromate | $Cd(BrO_3)_2.H_2O$ | 386. 26 | White rhombic | 3. 758 | D. |
| Chlorate | $Cd(ClO_3)_2.2H_2O$ | 315. 36 | Colorless prismatic deliquescent. | 2. 28 | 80 |
| Cobaltinitrite | $Cd_3(_6Co(NO_2)_6)_2$ | 1, 007. 21 | Yellow | | D. 175 |
| Dithionate | $CdS_2O_6.6H_2O$ | 380. 63 | Triclinic | 2. 272 | D. |
| Fluoride | $CdF_2$ | 150. 41 | White cubic | 6. 64 | 520 |
| Fluosilicate | $CdSiF_6.6H_2O$ | 362. 57 | Colored hexagonal | | |
| Formate | $Cd(HCO_2)_2.2H_2O$ | 238. 48 | Monoclinic | 2. 44 | D. |
| Iodate | $Cd(IO_3)_2$ | 462. 25 | White | 6. 43 | Tr. 160 |
| | $Cd(IO_3)_2.H_2O$ | 480. 27 | Small monoclinic | | |
| Lactate | $Cd(C_3H_5O_3)_2$ | 290. 55 | Needles | | |
| Oxalate | $CdC_2O_4$ | 200. 43 | Colorless | 3. 32 | D. 340 |
| | $CdC_2O_4.3H_2O$ | 254. 48 | do | | D. |
| Permanganate | $Cd(MnO_4)_2.6H_2O$ | 458. 37 | | 2. 81 | D. 95 |
| Orthophosphate | $Cd_3(PO_4)_2$ | 527. 19 | Colorless amorphous | | 1500 |
| Pyrophosphate | $Cd_2P_2O_7.2H_2O$ | 434. 81 | White powder | 4. 965 | 900 (anh.) |
| Potassium iodide | $CdI_2.2KI.2H_2O$ | 734. 31 | White deliquescent | 3. 359 | |
| Selenate | $CdSeO_4.2H_2O$ | 291. 4 | Rhombic | 3. 632 | D. 100 |
| Selenide | $CdSe$ | 191. 37 | Gray-brown hexagonal | 5. 81 | 1350 |
| Silicate | $CdSiO_3$ | 188. 47 | Rhombic | 4. 93 | 1242 |
| Sulfite | $CdSO_3$ | 192. 47 | White | | D. |
| Telluride | $CdTe$ | 240. 02 | Black cubic | 6. 20 | 1041 |
| Tungstate | $CdWO_4$ | 360. 33 | Yellow rhombic | | |

[1] Abbreviations used in the table: d., Decomposed; tr., transition; anh., anhydrous.

# SUBSTITUTES

Since most cadmium is consumed by the electroplating industry, it can sometimes be replaced by zinc or nickel and chromium. Nevertheless, most substitute metals lack the throwing power of cadmium necessary for electroplating odd shapes and parts. Zinc can be used instead of cadmium in electroplating; but for some uses, such as in salt water and tropical atmospheres, cadmium is much more satisfactory. However, the Navy Department has recently revised its specifications and now allows some articles to be zinc plated that previously had to be cadmium plated. Unlike many other electroplated coatings (such as copper, tin, nickel, and chromium), both cadmium and zinc protect steel- and copper-alloy basis metals electrochemically. Because of this, metals other than zinc, when substituted for cadmium, must be

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applied in appreciably greater thicknesses to give equal protection.

In solders and low-melting alloys, tin and bismuth may be substituted, and in bearings tin is a satisfactory substitute. However, during emergency periods tin frequently has been in shorter supply than cadmium.

Lead, zinc, and barium chromates can replace cadmium sulfide as pigments in many instances but are not as desirable, since they are attacked by hydrogen sulfide and other contaminants of the air in industrial neighborhoods.

# UNITED STATES SUPPLY—DISTRIBUTION

The supply of cadmium available to the United States consists of primary-metal production, an output of primary compounds, recovered secondary-metal compounds, and imports of metallic cadmium. Distribution consists of domestic consumption of primary and secondary metal and compounds and exports of metal (table 5). To balance supply and distribution, account must be taken of stock changes. Except for 1940–44, consumption data are apparent consumption, gaged by adding the production of primary metal and compounds and net imports of metal and adjusting for producers', distributors', compound manufacturers', and Government (when available for publication) stock changes. Shipments of secondary metal and compounds are not included in apparent consumption.

An historical review of supply-distribution trends (tables 4 and 5) shows the rapid rate at which production and consumption have increased since the cadmium industry in the United States started. The following sections of this chapter discuss these factors in detail.

TABLE 4.—*Cadmium supply of the United States, 1925–55*

(Thousand pounds of contained cadmium)

| Year | Production | | | Imports (metal) [4] | Total |
|---|---|---|---|---|---|
| | Primary metal [1] | Primary compounds [2] | Secondary [3] | | |
| 1925 | 503 | 113 | (*) | | 616 |
| 1926 | 810 | 167 | (*) | | 977 |
| 1927 | 1,075 | 229 | (*) | 22 | 1,326 |
| 1928 | 1,876 | 240 | (*) | 233 | 2,349 |
| 1929 | 2,481 | 433 | (*) | 214 | 3,128 |
| 1930 | 2,778 | 316 | (*) | 40 | 3,134 |
| 1931 | 1,051 | 337 | (*) | [5] | 1,388 |
| 1932 | 800 | 260 | (*) | | 1,060 |
| 1933 | 2,277 | 401 | (*) | 109 | 2,787 |
| 1934 | 2,777 | 567 | (*) | 126 | 3,470 |
| 1935 | 3,477 | 507 | (*) | 185 | 4,169 |
| 1936 | 3,633 | 627 | (*) | 576 | 4,836 |
| 1937 | 4,266 | 419 | (*) | 828 | 5,513 |
| 1938 | 4,078 | 216 | (*) | 33 | 4,327 |
| 1939 | 4,411 | 379 | [6] | 310 | 5,100 |
| 1940 | 6,154 | 209 | 228 | 28 | 6,619 |
| 1941 | 6,938 | 296 | 380 | 147 | 7,761 |
| 1942 | 7,323 | 48 | 316 | 53 | 7,740 |
| 1943 | 8,396 | 71 | 162 | 49 | 8,678 |
| 1944 | 8,454 | 326 | 107 | 67 | 8,954 |
| 1945 | 7,933 | 451 | 73 | 29 | 8,486 |
| 1946 | 6,200 | 271 | 355 | 17 | 6,843 |
| 1947 | 8,007 | 501 | 105 | 20 | 8,633 |
| 1948 | 7,583 | 193 | 121 | 10 | 7,907 |
| 1949 | 8,024 | 203 | 384 | 157 | 8,768 |
| 1950 | 8,850 | 341 | 427 | 630 | 10,248 |
| 1951 | 8,114 | 197 | 168 | 90 | 8,569 |
| 1952 | 8,388 | 179 | 80 | 1,479 | 10,126 |
| 1953 | 9,682 | 85 | 70 | 1,555 | 11,392 |
| 1954 | 9,416 | 136 | 138 | 402 | 10,092 |
| 1955 | 9,754 | [7] | 286 | 927 | 10,967 |

* Not available.
[1] Each year since about 1940, more than one-half of the primary metal has been derived from imported raw material; in earlier years foreign sources were not as significant.
[2] Excludes compounds made from metal.
[3] Metal and compounds (cadmium content) not produced from metal.
[4] Metallic cadmium imported for consumption.
[5] Less than 1,000 pounds.
[6] Included with primary compounds.
[7] Bureau of Mines not at liberty to publish.

TABLE 5.—*Distribution of cadmium in the United States, 1929–55, in thousand pounds of contained cadmium*

| Year | Apparent consumption (primary) | Secondary shipments | Exports (metal) | Total distribution |
|---|---|---|---|---|
| 1929 | 3,129 | (*) | | 3,129 |
| 1930 | 3,134 | (*) | | 3,134 |
| 1931 | 1,388 | (*) | | 1,388 |
| 1932 | 1,059 | (*) | | 1,059 |
| 1933 | 2,787 | (*) | | 2,787 |
| 1934 | 3,470 | (*) | | 3,470 |
| 1935 | 4,169 | (*) | | 4,169 |
| 1936 | 4,836 | (*) | | 4,836 |
| 1937 | 5,923 | (*) | | 5,923 |
| 1938 | 4,073 | (*) | 458 | 4,531 |
| 1939 | 5,900 | (*) | | 5,900 |
| 1940 | [1] 6,178 | [2] 227 | 287 | 6,465 |
| 1941 | [1] 7,766 | [2] 377 | 66 | 7,832 |
| 1942 | [1] 7,659 | [2] 305 | 251 | 7,910 |
| 1943 | [1] 7,381 | [2] 188 | 157 | 7,538 |
| 1944 | [1] 8,865 | [2] 107 | 548 | 9,413 |
| 1945 | 8,642 | 68 | 102 | 8,812 |
| 1946 | 6,983 | 361 | 140 | 7,484 |
| 1947 | 7,727 | 135 | 303 | 8,165 |
| 1948 | 7,797 | 121 | 956 | 8,874 |
| 1949 | 7,486 | 384 | 566 | 8,436 |
| 1950 | 9,546 | 427 | 353 | 10,326 |
| 1951 | 7,171 | 88 | 606 | 7,865 |
| 1952 | 9,008 | 123 | [3] 301 | 9,432 |
| 1953 | 9,570 | 60 | [3] 66 | 9,696 |
| 1954 | 7,424 | 149 | [3] 999 | 8,572 |
| 1955 | [4] 10,689 | 286 | [3] 1,394 | 12,369 |

* Not available.
[1] Consumption survey (authorized by War Production Board).
[2] Not included in total, because secondary was covered by consumption survey.
[3] Includes metal, dross, flue dust, residues, scrap, and alloys.
[4] Primary compounds not included inasmuch as Bureau of Mines is not at liberty to publish these data.

## PRODUCTION

### PRIMARY METAL

The United States is the world's leading producer of cadmium by a wide margin; approximately two-thirds of the total world output is produced at domestic plants. United States production, however, is not solely from domestic materials. It is estimated that, since 1940, about 60 percent of the primary cadmium

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metal produced in the United States was of foreign origin, obtained from imported flue dust and imported zinc, lead, and copper ores and concentrates. Mexico was the chief foreign source of ores and concentrates containing cadmium, followed by Canada and Peru.

Tables 6 and 7 present estimates of the quantities and percentages of primary cadmium derived from domestic ores, foreign ores, and imported flue dusts since 1940.

TABLE 6.—*Primary cadmium-metal production at United States plants from domestic materials, 1940–55*

| Year | Domestic mine production of recoverable zinc, short tons | Estimated cadmium recovered from domestic zinc, thousand pounds | Estimated cadmium recovered per ton of domestic zinc, pounds | Estimated percentage of U. S. output of cadmium from domestic ores |
|---|---|---|---|---|
| 1940 | 665,100 | 3,000 | | 47 |
| 1941 | 749,100 | 3,240 | | 45 |
| 1942 | 768,000 | 3,300 | 4.4 | 45 |
| 1943 | 744,200 | 3,300 | | 39 |
| 1944 | 718,600 | 3,250 | | 37 |
| 1945 | 614,400 | 2,750 | | 33 |
| 1946 | 574,800 | 2,550 | | 39 |
| 1947 | 637,600 | 3,000 | | 35 |
| 1948 | 630,000 | 2,960 | 5.1 | 38 |
| 1949 | 593,200 | 3,200 | | 39 |
| 1950 | 623,400 | 3,900 | | 42 |
| 1951 | 681,200 | 3,500 | | 42 |
| 1952 | 666,000 | 3,000 | | 35 |
| 1953 | 547,000 | 2,980 | 5.7 | 31 |
| 1954 | 473,000 | 3,700 | | 39 |
| 1955 | 515,000 | 3,350 | | 34 |

TABLE 7.—*Primary cadmium metal production at United States plants from foreign materials, 1940–55*

| Year | Recoverable zinc from U. S. imports of ores and concentrates, short tons [1] | Estimated cadmium recovered from imports of zinc ore, thousand pounds | Estimated cadmium recovered per ton from foreign zinc ore, pounds | Cadmium recovered from imported flue dust, thousand pounds | Estimated percentage of U. S. output of cadmium from: Imported ores and concentrates | Estimated percentage of U. S. output of cadmium from: Imported flue dust |
|---|---|---|---|---|---|---|
| 1940 | 153,300 | 1,660 | | 1,707 | 26 | 27 |
| 1941 | 245,800 | 1,950 | | 2,044 | 27 | 28 |
| 1942 | 313,100 | 2,520 | 9.4 | 1,550 | 34 | 21 |
| 1943 | 456,400 | 3,690 | | 1,475 | 44 | 19 |
| 1944 | 359,300 | 3,990 | | 1,540 | 46 | 17 |
| 1945 | 324,400 | 3,640 | | 1,995 | 43 | 24 |
| 1946 | 231,200 | 2,440 | | 1,485 | 38 | 23 |
| 1947 | 253,300 | 3,320 | | 2,190 | 39 | 26 |
| 1948 | 224,600 | 3,120 | 13.6 | 1,700 | 40 | 22 |
| 1949 | 205,000 | 3,340 | | 1,685 | 41 | 20 |
| 1950 | 263,900 | 3,770 | | 1,525 | 41 | 17 |
| 1951 | 257,400 | 3,280 | | 1,530 | 40 | 18 |
| 1952 | 382,200 | 3,680 | | 1,890 | 43 | 22 |
| 1953 | 436,700 | 5,000 | 11.3 | 1,770 | 51 | 18 |
| 1954 | 389,100 | 4,440 | | 1,408 | 47 | 14 |
| 1955 | 406,300 | 4,670 | | 1,741 | 48 | 18 |

[1] Calculated as 85 percent of zinc content.

Large quantities of cadmium flue dust were obtained from Mexico for many years before 1940 for processing at United States plants. It has only been since around 1940, when United States imports of zinc and lead ores and concentrates first became important, that a substantial portion of United States cadmium production has been obtained from other foreign sources than Mexico. The ratio of metal production at domestic plants from domestic materials to production from foreign materials, therefore, was much higher before imports attained significant proportions than it has been since then.

Metallic cadmium was first produced in the United States in 1906, and by 1917 the United States had become the world's largest producer. Production increased rapidly as new uses for the metal were discovered and improved recovery techniques were introduced. Output was 207,000 pounds in 1917, by 1925 it had more than doubled, and by 1931 it was more than 10 times that figure. Following a drop to 800,000 pounds in 1932 (owing to the extremely low production of zinc), cadmium-metal output continued its upward trend and by 1939, was produced at a rate of nearly 4.4 million pounds a year. The production of cadmium during 1933–39 was well above the average yearly output for 1925–29, whereas mine production of recoverable zinc during the 1930's was considerably below the 1925–29 average; these facts highlight the improvement in cadmium-recovery practice that occurred in the relatively short period.

Primary cadmium production for 1941–45 averaged 7.8 million pounds. This significant increase was attributed to the huge increases in imports of zinc ores and concentrates during World War II, from which large quantities of cadmium were recovered. Output declined to 6.2 million pounds in 1946 and then trended upward to the 1955 high of 9.7 million pounds, under the impetus of increasing demand for the metal.

## PRIMARY COMPOUNDS

In addition to metal production, comparatively small quantities of cadmium compounds (largely cadmium sulfide) made directly from primary materials are produced in the United States and contribute to the total available supply of cadmium. The production of primary compounds varies considerably from year to year; the high was 501,000 pounds in 1947 and the low 48,000 pounds in 1942. The average yearly production for 1940–55 was about 241,000 pounds. No distinction was made between compound production from primary materials and output from metal (not an addition to total supply) before 1937. The production of cadmium oxide and cadmium sulfide from both primary sources and from metal is shown for 1940–55 in table 8.

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TABLE 8.—*Cadmium oxide and cadmium sulfide produced in the United States, 1940–55*

(Thousand pounds)

| Year | Oxide [1] | | Sulfide [2] | |
|---|---|---|---|---|
| | Gross weight | Cadmium content | Gross weight | Cadmium content |
| 1940 | 352 | 279 | 2,288 | 760 |
| 1941 | 444 | 389 | 3,304 | 1,142 |
| 1942 | 633 | 553 | 1,001 | 300 |
| 1943 | 537 | 470 | 672 | 227 |
| 1944 | 571 | 500 | 1,312 | 467 |
| 1945 | 439 | 384 | 1,732 | 638 |
| 1946 | 364 | 318 | 3,637 | 1,226 |
| 1947 | 450 | 393 | 3,502 | 1,308 |
| 1948 | 335 | 292 | 3,137 | 1,097 |
| 1949 | 571 | 498 | 2,632 | 999 |
| 1950 | 580 | 505 | 4,384 | 1,571 |
| 1951 | 606 | 529 | 3,118 | 956 |
| 1952 | 608 | 531 | 2,666 | 899 |
| 1953 | 1,094 | 956 | 3,920 | 1,229 |
| 1954 | 959 | 838 | 3,470 | 1,046 |
| 1955 | [3] | [3] | 4,191 | 1,348 |

[1] Includes cadmium oxide used in making other compounds, 1940–44.
[2] Includes cadmium lithopone and cadmium sulfoselenide.
[3] Bureau of Mines not at liberty to publish figures.

## SECONDARY METAL AND COMPOUNDS

Relatively small quantities of cadmium metal and compounds are recovered from secondary materials. Production is variable and comprises only a minor portion of total supply. The largest quantity produced—427,000 pounds—was in 1950 and the smallest—70,000 pounds—in 1953. For 1940–54 production averaged 208,000 pounds a year. Data before 1940 are not available.

## COMPOUNDS

Numerous cadmium compounds (the most important of which are cadmium oxide and cadmium sulfide) are produced in the United States, principally from metallic cadmium. Substantial quantities of compounds, however, are manufactured from primary and secondary raw materials, as previously mentioned, and only this quantity is an addition to the total supply. Descriptions of the cadmium compounds manufactured, mostly in small quantities, are given on pages 21 through 25. Data on output are not available for cadmium compounds other than oxide and sulfide.

# CONSUMPTION

## PRIMARY METAL AND COMPOUNDS

Cadmium was first used primarily in paint pigments and low-melting-point alloys. After development of cadmium electroplating around 1919, demand increased markedly. Further, in the 1930's there was considerable expansion in the use of bearing alloys containing cadmium. Cadmium consumption increased from about 100,000 pounds in 1919 to more than 600,000 pounds in 1925 and advanced spectacularly to 3 million pounds in 1929; by 1940 the total had more than doubled.

Stimulated by the national defense program, consumption rose to 7.8 million pounds in 1941 and, owing to the great demand for military purposes, increased during World War II, averaging 8.1 million pounds a year for 1942–45. In 1950 apparent consumption reached a new high—9.5 million pounds—chiefly because of the large defense demands generated by the war in Korea. Consumption of cadmium in 1951 was curtailed enough to enable available supplies to meet all military and essential civilian requirements, despite a 24-percent decrease in total supply. Domestic utilization declined to 7.2 million pounds, owing largely to restrictions placed on end uses by the National Production Authority Cadmium Conservation Order of January 1, 1951. This order was revised May 15, 1952, and consumption of primary cadmium in 1952 increased 26 percent to 9 million pounds. In 1953 a new peak of 9.6 million pounds was established. In 1954 apparent consumption declined to about 7.5 million pounds, but in 1955 consumption of 10.7 million pounds exceeded that in any previous years. During 1948–55 apparent consumption included large purchases of cadmium by the Federal Government for the national stockpile; hence the true domestic consumption for those years was considerably less than the apparent quantity consumed.

TABLE 9.—*United States imports for consumption of cadmium flue dust (cadmium content), 1936–55*

(Thousand pounds)

[U. S. Department of Commerce]

| Year | Mexico | Others | Total [1] |
|---|---|---|---|
| 1936 | 1,200 | ..... | 1,200 |
| 1937 | 1,366 | ..... | 1,366 |
| 1938 | 1,677 | ..... | 1,677 |
| 1939 | 1,704 | ..... | 1,704 |
| 1940 | 1,891 | ..... | 1,891 |
| 1941 | 1,984 | [2] 337 | 2,321 |
| 1942 | 1,724 | ..... | 1,724 |
| 1943 | 1,643 | ..... | 1,643 |
| 1944 | 1,689 | ..... | 1,689 |
| 1945 | 2,193 | ..... | 2,193 |
| 1946 | 1,609 | [3] 44 | 1,653 |
| 1947 | 2,356 | ..... | 2,356 |
| 1948 | 1,828 | [4] | 1,828 |
| 1949 | 1,787 | [5] 3 | 1,790 |
| 1950 | 1,602 | ..... | 1,602 |
| 1951 | 1,607 | ..... | 1,607 |
| 1952 | 1,985 | [6] 7 | 1,992 |
| 1953 | 1,865 | ..... | 1,865 |
| 1954 | 1,483 | ..... | 1,483 |
| 1955 | 1,833 | ..... | 1,833 |

[1] Cadmium content estimated as 90 percent recoverable through 1948; improved recovery methods since then have raised it to 95 percent.
[2] South-West Africa, 334,000 pounds; Union of South Africa, 3,000 pounds.
[3] Netherlands.
[4] Australia, 600 pounds.
[5] Brazil.
[6] Canada, 3,000 pounds; Peru, 4,000 pounds.

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## SECONDARY SHIPMENTS

In addition to primary consumption, shipments of secondary metal and compounds to consumers are included in total distribution. Data before 1940 are not available, and for 1940–44 the consumption survey included secondary as well as primary metal and compounds. For 1945–54 shipments averaged around 191,000 pounds a year, or approximately the same as average production.

## FOREIGN TRADE

The United States depends upon foreign sources for approximately 45 to 65 percent of its annual cadmium requirements. It is estimated that since 1940 about 60 percent of the primary metallic cadmium produced at United States plants was of foreign origin. The cadmium content of imported flue dust is recorded; but the content of imported zinc ores and concentrates (from which approximately 60 percent of the cadmium of foreign origin is obtained) is only estimated. (See tables 6 and 7.)

Almost all of the imported flue dust and a large proportion of the zinc ores and concentrates are obtained from Mexico. Canada and Peru are other important sources of cadmium-bearing materials. Substantial quantities of zinc ores and concentrates containing cadmium were also obtained from other countries, notably Australia, Argentina, Belgian Congo, Bolivia, Chile, South-West Africa, and Spain during 1940–55. Tables 9 and 10 show imports of cadmium flue dust for 1936–55 and imports of zinc ores and concentrates for 1940–55, by countries. Before 1940 the quantity of cadmium recovered from imports of zinc-bearing raw materials was small.

TABLE 10.—*United States general imports of zinc ores and concentrates (zinc content), by countries, 1940–55*

(Thousand short tons)

[U. S. Department of Commerce]

| | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 |
|---|---|---|---|---|---|---|---|---|
| Argentina | 7 | 21 | 23 | 54 | 22 | | 8 | |
| Australia | 2 | 9 | 32 | 122 | 42 | 15 | 4 | 1 |
| Belgian Congo | | 13 | 3 | 15 | | | | |
| Bolivia | 3 | 3 | 6 | 3 | 5 | 6 | 26 | 17 |
| Canada [1] | 58 | 57 | 109 | 143 | 131 | 114 | 57 | 51 |
| Chile | 1 | 2 | 7 | 14 | | 34 | | |
| Italy | | | | | | | | 12 |
| Japan | | | | | | | | |
| Yugoslavia | | | | | | | | |
| Mexico | 94 | 148 | 161 | 166 | 178 | 177 | 128 | 164 |
| Peru | 17 | 29 | 28 | 22 | 44 | 35 | 49 | 50 |
| Spain | | 8 | | | | | | 3 |
| Union of South Africa | | | | | | | | |
| Others | | | | | | | | |
| Total | 182 | 290 | 369 | 539 | 424 | 381 | 272 | 298 |

| | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|---|---|---|
| Argentina | | | | 6 | 1 | | | |
| Australia | 1 | 5 | 2 | 3 | 2 | 11 | 2 | 6 |
| Belgian Congo | | | | | | | | |
| Bolivia | 5 | 4 | 4 | 8 | 15 | 23 | 11 | 2 |
| Canada [1] | 65 | 61 | 78 | 97 | 149 | 166 | 157 | 173 |
| Chile | | | | 1 | | 3 | 2 | 5 |
| Italy | 11 | | | | | 9 | | |
| Japan | 5 | | | | 1 | | | |
| Yugoslavia | | | | 2 | 3 | 11 | 5 | |
| Mexico | 142 | 144 | 155 | 144 | 201 | 169 | 176 | 187 |
| Peru | 23 | 15 | 17 | 29 | 44 | 84 | 93 | 83 |
| Spain | 9 | 5 | 18 | 4 | 17 | 9 | | |
| Union of South Africa | 2 | 7 | 4 | 3 | 5 | 13 | 4 | 5 |
| Others | 2 | 1 | 1 | 7 | 12 | 16 | 5 | 17 |
| Total | 265 | 242 | 279 | 304 | 450 | 514 | 455 | 478 |

[1] Includes Newfoundland and Labrador.

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TABLE 11.—*United States imports for consumption of cadmium metal, by countries, 1941–55*

(Thousand pounds)

[U. S. Department of Commerce]

| Year | Australia | Belgian Congo | Belgium-Luxembourg | Canada | Egypt | West Germany | Italy | Japan | Netherlands | New Zealand | Norway | Peru | United Kingdom | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1941 | | 53 | | 136 | | | | | | | | | 11 | 200 |
| 1942 | | 40 | | | | | | | | | | | | 53 |
| 1943 | | 40 | | | | | | | | | | 9 | | 49 |
| 1944 | | 53 | | | | | 9 | | | | | 5 | | 67 |
| 1945 | | 26 | | 1 | | | | | | | | 2 | | 29 |
| 1946 | | 7 | 2 | 4 | | | | | | | | 5 | | 18 |
| 1947 | | | 2 | 15 | | | | | | | | 4 | | 21 |
| 1948 | | | | 6 | | | | | | | | 4 | | 10 |
| 1949 | 7 | | 49 | 68 | | | | 32 | | | | 2 | | 158 |
| 1950 | 8 | | 144 | 238 | 1 | | 4 | 195 | 34 | 2 | | 3 | 1 | 630 |
| 1951 | 10 | | 53 | 3 | | | | 19 | 5 | | | | | 90 |
| 1952 | | | 1,195 | 10 | | 6 | | 267 | | | | | | 1,478 |
| 1953 | 123 | | 537 | 509 | | 4 | 66 | 211 | 3 | 25 | 66 | 11 | | 1,555 |
| 1954 | 55 | | 93 | 159 | | | 22 | 44 | | | | 29 | | 402 |
| 1955 | | | 176 | 565 | | | 66 | 38 | 55 | | | 28 | | 928 |

United States imports of metallic cadmium have been relatively unimportant in proportion to the total supply of cadmium available for consumption, except for 1952–53, when record quantities (1,479,000 and 1,555,000 pounds, respectively) were imported. The 1953 total was more than 14 times greater than the 1940–51 yearly average (108,000 pounds).

Exports of metallic cadmium from the United States have never been large compared with the quantities consumed domestically. During 1940–51, exports averaged 381,000 pounds a year—less than 5 percent of apparent consumption. Exports vary widely from year to year and in recent years have ranged from 66,000 pounds in 1953 to 1,394,000 pounds in 1955. Countries in Western Europe received the bulk of United States exports during World War II and the postwar years—the only time when exports were significant.

The tariff on imported cadmium metal is 3¾ cents a pound, as established by the Geneva Trade Conference of 1947. Cadmium contained in flue dust is admitted free.

United States imports and exports of metallic cadmium are included in tables 11 and 12, respectively.

## STOCKS

There are several classifications of cadmium stocks—producers' stocks of metal, compound manufacturers' and distributors' stocks of metal and compounds, consumers' (other than compound manufacturers) stocks of metal and cadmium contained in compounds, and Govern-

TABLE 12.—*United States cadmium-metal exports, by countries, 1948–55* [1]

(Pounds)

[United States Department of Commerce]

| | 1948 | 1949 | 1950 | 1951 | [1] 1952 | [1] 1953 | [1] 1954 | [1] 1955 |
|---|---|---|---|---|---|---|---|---|
| Argentina | 4,700 | 2,200 | 1,200 | 600 | 2,300 | | | 6,800 |
| Austria | 8,900 | 7,400 | 1,100 | | | | | |
| Belgium-Luxembourg | 75,700 | 19,500 | 2,600 | | | | 20,600 | 17,900 |
| Brazil | 900 | 1,200 | 400 | 4,300 | 1,900 | 400 | 14,600 | 800 |
| Canada | 42,100 | 6,600 | 4,800 | 1,300 | 11,600 | 22,000 | 29,400 | 6,900 |
| Chile | 500 | 900 | | 1,300 | 2,500 | 2,800 | | |
| France | 225,900 | 254,200 | 72,700 | 253,300 | 80,500 | | | 11,200 |
| Germany | 271,800 | 92,300 | 126,500 | 25,000 | 11,800 | 23,500 | 308,300 | 307,000 |
| Mexico | 2,000 | 6,800 | 3,000 | 4,300 | 5,100 | 3,300 | 9,900 | 12,600 |
| Netherlands | 73,100 | 39,700 | 9,000 | | 1,700 | 5,500 | 43,400 | 187,200 |
| Sweden | 29,000 | 31,300 | 31,600 | 11,500 | 3,600 | | 33,100 | 7,500 |
| Switzerland | 84,500 | 21,500 | | 3,700 | 1,100 | | 8,800 | 4,500 |
| United Kingdom | 116,600 | 46,600 | 97,400 | 296,000 | 169,500 | | 507,100 | 811,800 |
| Yugoslavia | 2,600 | 7,400 | 600 | 2,600 | 3,000 | 3,600 | 2,200 | 300 |
| Others | 17,400 | 28,500 | 2,000 | 2,300 | 6,300 | 4,800 | 21,600 | 19,400 |
| Total | 995,700 | 556,100 | 352,900 | 606,200 | 300,900 | 65,900 | 999,000 | 1,393,900 |

[1] Includes dross, flue dust, residues, scrap, and alloys as well as metal.

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TABLE 13.—*Cadmium stocks at end of year, 1940–55*

(Thousand pounds of contained cadmium)

| | 1940 | | | 1941 | | |
|---|---|---|---|---|---|---|
| | Metallic cadmium | Cadmium compounds | Total cadmium | Metallic cadmium | Cadmium compounds | Total cadmium |
| Producers | 552 | 67 | 619 | 452 | 104 | 556 |
| Compound manufacturers | 171 | 234 | 405 | 54 | 147 | 201 |
| Distributors [1] | 203 | 53 | 256 | 82 | 15 | 97 |
| Government | | | | 114 | | 114 |
| Total | 926 | 354 | 1,280 | 702 | 266 | 968 |
| Consumers [2] | 1,501 | 64 | 1,565 | 1,536 | 106 | 1,642 |

| | 1942 | | | 1943 | | |
|---|---|---|---|---|---|---|
| Producers | 388 | 89 | 477 | 406 | 22 | 428 |
| Compound manufacturers | 12 | 124 | 136 | 30 | 92 | 122 |
| Distributors [1] | 131 | 28 | 159 | 410 | 37 | 447 |
| Government | 201 | | 201 | 1,430 | | 1,430 |
| Total | 732 | 241 | 973 | 2,276 | 151 | 2,427 |
| Consumers [2] | 1,283 | 83 | 1,366 | 911 | 69 | 980 |

| | 1944 | | | 1945 | | |
|---|---|---|---|---|---|---|
| Producers | 307 | 63 | 370 | 246 | | 246 |
| Compound manufacturers | 12 | 63 | 75 | 12 | 123 | 135 |
| Distributors [1] | 359 | 63 | 422 | 390 | 45 | 435 |
| Government | 1,190 | | 1,190 | 907 | | 907 |
| Total | 1,868 | 189 | 2,057 | 1,555 | 168 | 1,723 |
| Consumers [2] | 924 | 46 | 970 | [3] | [3] | [3] |

| | 1946 | | | 1947 | | |
|---|---|---|---|---|---|---|
| Producers | 260 | | 260 | 444 | | 444 |
| Compound manufacturers | 25 | 76 | 101 | 27 | 215 | 242 |
| Distributors [1] | 126 | 22 | 148 | 319 | 49 | 368 |
| Government | 581 | | 581 | 484 | | 484 |
| Total | 992 | 98 | 1,090 | 1,274 | 264 | 1,538 |

| | 1948 | | | 1949 | | |
|---|---|---|---|---|---|---|
| Producers | 352 | | 352 | 502 | | 502 |
| Compound manufacturers | 8 | 88 | 96 | 10 | 164 | 174 |
| Distributors [1] | 83 | 39 | 122 | 185 | 40 | 225 |
| Total [4] | 443 | 127 | 570 | 697 | 204 | 901 |

| | 1950 | | | 1951 | | |
|---|---|---|---|---|---|---|
| Producers | 512 | | 512 | 860 | | 860 |
| Compound manufacturers | 15 | 187 | 202 | 58 | 247 | 305 |
| Distributors [1] | 48 | 61 | 109 | 205 | 79 | 284 |
| Total [4] | 575 | 248 | 823 | 1,123 | 326 | 1,449 |

| | 1952 | | | 1953 | | |
|---|---|---|---|---|---|---|
| Producers | 1,503 | | 1,503 | 3,047 | | 3,047 |
| Compound manufacturers | 189 | 225 | 414 | 77 | 417 | 494 |
| Distributors [1] | 202 | 67 | 269 | 256 | 75 | 331 |
| Total [4] | 1,894 | 292 | 2,186 | 3,380 | 492 | 3,872 |

| | 1954 | | | 1955 | | |
|---|---|---|---|---|---|---|
| Producers | 4,542 | | 4,542 | 3,129 | | 3,129 |
| Compound manufacturers | 99 | 469 | 568 | 129 | 301 | 430 |
| Distributors [1] | 244 | 49 | 293 | 359 | 83 | 442 |
| Total [4] | 4,885 | 518 | 5,403 | 3,617 | 384 | 4,001 |
| Consumers | 738 | 152 | 891 | 784 | 193 | 977 |

[1] Comprises largest dealers.
[2] Partly estimated. Includes some material in process. Excludes stocks of compounds held by pigment and chemical consumers, 1940–44.
[3] Consumers' stocks, 1945–53, not available.
[4] Excludes national strategic stockpile, 1948–55.

ment stocks of metal. Table 13 shows stocks of cadmium for 1940–55. The quantity of cadmium in the strategic stockpile, purchased in 1948–55, may not be divulged. Data on consumers' stocks are not available for 1945–53; the stocks of metal and compounds (metal content) together are believed to have been maintained at 1 million pounds a year for the period.

Excluding Government and consumers' inventories, stocks reached an alltime high of 5,403,000 pounds at the end of 1954, culminating a rapid rise that began in 1951. Producers' stocks (accounting for more than three-fourths of the total) were about 4 million pounds higher than the quantity that producers normally hold or would like to keep on hand. The increase of 1.5 million pounds in total stocks in 1954 was brought about by maintenance of high-level cadmium production. At the same time, business activity declined in those industries that consume cadmium; for example, production of automobiles in 1954 was down 9 percent, and that of trucks and busses was 14 percent below 1953.

In the war years (1941–45) year-end stocks, excluding consumers' and Government supplies, averaged 861,000 pounds, or slightly more than 1 month's supply, based on the average yearly consumption for those years. Total stocks at the end of 1954 were adequate for nearly 9 months' consumption at the 1954 rate of use.

## MARKETING AND PRICES

Cadmium is commonly sold as sticks, bars, balls, and, to a smaller extent, ingots. Much metal is also marketed as anodes, or special platers' shapes, which command a premium of approximately 5 to 10 percent above the price for regular shapes. Quotations usually are on a delivered basis.

The American Society for Testing Materials has no specifications for cadmium. Although attempts have been made in recent years to establish market requirements of more restricted and uniform nature, standards have not yet been promulgated. Platers are rather lenient with regard to lead (0.05 percent maximum) but are insistent on limiting the thallium content to 0.005 percent. Bearing manufacturers are willing to accept up to 0.05 percent thallium but limit the lead content to 0.02 percent. Some marketing specifications are shown below:

*Bureau of Federal Supply*

| | Percentage | |
|---|---|---|
| Cadmium | 99.90 | min. |
| Copper | .01 | max. |
| Iron | .01 | max. |
| Lead + silver + tin | .05 | max. |
| Zinc | .05 | max. |
| Antimony + arsenic + thallium | .005 | max. |

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*Plating industry*

| | Percentage |
|---|---|
| Cadmium | 99.90 min. |
| Lead+silver+tin | .05 max. |
| Antimony+arsenic+thallium | .005 max. |

*Bearing manufacturers*

(*A*)

| | |
|---|---|
| Cadmium+zinc | 99.90 min. |
| Zinc | .10 max. |
| Copper | .02 max. |
| Lead | .02 max. |
| Bismuth | .01 max. |
| Antimony | .01 max. |
| Tin | .005 max. |

(*B*)

| | |
|---|---|
| Cadmium | Remainder |
| Copper | 0.40–0.60 |
| Silver | .60–.80 |
| Nickel | .25 max. |
| Lead | .02 max. |
| Zinc | .05 max. |
| Tin | .02 max. |

Cadmium is a fairly expensive metal; for 1925–55 prices ranged from 10 to 20 times that of zinc. The quoted selling price of commercial cadmium sticks increased more than 300 percent from 1939 to 1951, whereas the real price increased only 88 percent (see table 14). Comparison of the 5-year period, 1936–40, with 1951–55 shows a change of only 8 percent in the real price compared with a change of 134 percent in the quoted selling price.

During World War II the Office of Price Administration fixed the price at 90 cents a pound.

TABLE 14.—*Cadmium-metal prices in New York, 1936–55*

(Price per pound for sticks and bars)

| Year | Average price [1] | Real price (1954=100) [2] |
|---|---|---|
| 1936 | $0.92 | $1.93 |
| 1937 | 1.30 | 2.55 |
| 1938 | .82 | 1.77 |
| 1939 | .59 | 1.30 |
| 1940 | .80 | 1.73 |
| 1941 | .88 | 1.71 |
| 1942 | .90 | 1.55 |
| 1943 | .90 | 1.48 |
| 1944 | .90 | 1.47 |
| 1945 | .90 | 1.44 |
| 1946 | 1.10 | 1.54 |
| 1947 | 1.72 | 1.97 |
| 1948 | 1.83 | 1.93 |
| 1949 | 2.00 | 2.22 |
| 1950 | 2.17 | 2.32 |
| 1951 | 2.55 | 2.45 |
| 1952 | 2.44 | 2.41 |
| 1953 | 2.00 | 2.00 |
| 1954 | 1.73 | 1.73 |
| 1955 | 1.70 | 1.69 |

[1] Source: American Metal Market, Metal Statistics.
[2] Average price deflated by wholesale price index.

# FOREIGN SUPPLY—DISTRIBUTION

Analysis of the world supply-distribution position in cadmium is beset by several difficulties, chief of which is lack of comprehensive data on consumption. Production statistics are, for the most part, available; but except for a few countries, consumption figures are lacking. Whether shortages or surpluses exist depends to a large degree upon activity in the United States, which is by far the leading world producer and consumer. During World War II and again in 1950–51 cadmium was in short supply due to the demand generated by war and defense efforts. Foreign producers obtained premiums for cadmium sold in the United States in 1950–51, while in 1952–53 imported cadmium sold at discounts.

In 1953 world production (excluding eastern Europe) of primary metallic cadmium totaled about 14 million pounds, and apparent consumption (also excluding eastern Europe) was estimated at approximately 12 million pounds. Production in 1954 and 1955 was estimated at about 15 million and 17 million pounds, respectively.

## PRODUCTION

United States production of cadmium metal is not solely from domestic zinc ores; the output from these ores constitutes about 25 to 30 percent of the world total.

Other large producers of cadmium raw materials are, with one exception, leading zinc producers. The exception—South-West Africa—is not one of the larger zinc producers but, by virtue of the high cadmium content of the ore mined, ranks among the outstanding cadmium producers. South-West Africa exports lead-zinc-copper concentrates containing large quantities of cadmium, principally to the United States, the United Kingdom, Belgium, and France, where they are processed to recover the metal content.

Mexico ranks first as an import source of cadmium-bearing raw materials (zinc ore and flue dust). It is believed that, in some years, more cadmium was obtained from these materials than from United States ores. The concentration of cadmium in flue dust from Mexi-

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can lead- and zinc-smelting processes ranges from 5 to 70 percent.

Canada and Australia, both leading zinc producers, are important sources of cadmium. The bulk of Canada's output is recovered at Canadian plants, while about half of Australia's supplies are recovered at domestic plants, and half is contained in zinc and lead concentrates exported, chiefly to the United Kingdom, and recovered there.

Belgium and the United Kingdom—working exclusively on imported materials—are significant producers of refined cadmium. Japan, Norway, and Italy, operating on domestic materials, and France, treating imports, also produce sizable quantities of cadmium metal.

Germany formerly recovered large quantities of cadmium from the cadmium-rich zinc ore of Upper Silesia, but with cession of that territory to Poland after World War II Germany's output has declined considerably compared with prewar production. Poland and the U. S. S. R. produce relatively important quantities of cadmium. Production from these countries is mostly estimated. Other producers of metallic cadmium include Belgian Congo and Spain.

Peruvian lead and zinc concentrates contain appreciable quantities of cadmium. Concentrates are exported, chiefly to the United States, where the cadmium is recovered.

Table 15 shows world production of cadmium, by countries, for 1940–55.

TABLE 15.—*World production of primary cadmium metal, by principal countries, 1940–55*

(Thousand pounds)

| | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 |
|---|---|---|---|---|---|---|---|---|
| Australia | 386 | 430 | 366 | 400 | 598 | 542 | 511 | 461 |
| Belgian Congo | ------- | 7 | 60 | 51 | 47 | 40 | 36 | 57 |
| Belgium[1] | N. a. | [2] 51 | [2] 89 | [2] 70 | [2] 2 | N. a. | 196 | 190 |
| Canada | 908 | 1, 251 | 1, 149 | 787 | 527 | 646 | 803 | 718 |
| France | 220 | 44 | 22 | 22 | 12 | 15 | 104 | 95 |
| Germany | 653 | 820 | 536 | 608 | 460 | N. a. | 2 | 3 |
| Italy | 474 | 406 | 270 | 158 | 86 | 63 | 88 | 85 |
| Japan | N. a. | N. a. | [3] 225 | [3] 247 | [3] 187 | [3] 49 | 17 | 19 |
| Mexico[4] | 1, 798 | 1, 999 | 1, 883 | 1, 768 | 1, 504 | 2, 321 | 1, 581 | 1, 715 |
| Norway | 63 | 55 | 30 | 25 | 23 | 29 | 62 | 110 |
| Peru | ------- | ------- | 5 | 8 | 5 | 21 | 2 | 3 |
| Poland | 518 | 520 | 511 | 485 | 430 | 108 | 253 | 265 |
| South-West Africa[5] | 87 | 497 | ------- | ------- | ------- | ------- | ------- | ------- |
| Spain | ------- | ------- | ------- | ------- | ------- | ------- | ------- | ------- |
| U. S. S. R.[6] | 110 | 110 | 110 | 110 | 110 | 110 | 110 | 126 |
| United Kingdom | 403 | 327 | 351 | 417 | 455 | 491 | 268 | 234 |
| United States | 6, 154 | 6, 938 | 7, 323 | 8, 396 | 8, 453 | 7, 933 | 6, 200 | 8, 007 |

| | 1948 | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|---|---|---|
| Australia | 646 | 582 | 659 | 517 | 641 | 665 | 645 | 674 |
| Belgian Congo | 40 | 54 | 65 | 54 | 45 | 71 | 139 | 366 |
| Belgium[1] | 347 | 326 | 805 | 990 | 1, 210 | 1, 040 | 1, 100 | 1, 050 |
| Canada | 766 | 846 | 848 | 1, 327 | 949 | 1, 118 | 1, 087 | 1, 919 |
| France | 110 | 128 | 158 | 187 | 195 | 283 | 313 | 397 |
| Germany, West | 8 | 11 | 26 | 154 | 141 | 227 | 618 | 709 |
| Italy | 104 | 163 | 165 | 441 | 293 | 401 | 458 | 433 |
| Japan | 42 | 116 | 199 | 259 | 367 | 459 | 611 | 757 |
| Mexico[4] | 1, 995 | 1, 808 | 1, 519 | 1, 969 | 1, 618 | 2, 113 | 1, 130 | 2, 855 |
| Norway | 137 | 157 | 174 | 221 | 163 | 197 | 178 | 255 |
| Peru | 4 | 2 | 3 | ------- | 38 | 23 | 66 | 138 |
| Poland | 350 | [6] 529 | 530 | 400 | 420 | 485 | [5] 500 | [5] 550 |
| South-West Africa[5] | 1, 140 | 1, 662 | 1, 344 | 1, 434 | 1, 112 | 1, 194 | 1, 620 | 1, 402 |
| Spain | 12 | 11 | 10 | 9 | 12 | 16 | 21 | 22 |
| U. S. S. R.[6] | 128 | 128 | 150 | 180 | 225 | 275 | 300 | 330 |
| United Kingdom | 255 | 226 | 262 | 326 | 347 | 380 | 316 | 337 |
| United States | 7, 583 | 8, 023 | 8, 849 | 8, 114 | 8, 388 | 9, 682 | 9, 416 | 9, 754 |

[1] Estimated.
[2] Exports.
[3] Approximate.
[4] Content of flue dust exported for extraction elsewhere. Does not include recoverable cadmium content of zinc and lead ores and concentrates exported.
[5] Cadmium content of raw materials exported and reduced to metal elsewhere.
[6] Planned production.

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TABLE 16.—*Apparent consumption of cadmium in some foreign countries, 1941–55*

(Thousand pounds)

[Minerals et métaux, Société anonyme, Paris, France, Statistiques, 1950 and 1956]

| Year | Belgium-Luxembourg | Canada | France | Italy | Norway | United Kingdom |
|---|---|---|---|---|---|---|
| 1941 | N. a. | 298 | 44 | 253 | 10 | N. a. |
| 1942 | N. a. | 414 | 24 | 337 | 13 | 964 |
| 1943 | N. a. | 336 | 22 | 225 | 10 | 827 |
| 1944 | N. a. | 216 | 11 | N. a. | 5 | 844 |
| 1945 | N. a. | 174 | 262 | N. a. | 20 | 985 |
| 1946 | N. a. | 192 | 408 | 22 | 21 | 1, 216 |
| 1947 | 27 | 144 | 478 | 42 | [1] 17 | 1, 117 |
| 1948 | 33 | 186 | 551 | 60 | [1] 20 | 1, 199 |
| 1949 | 33 | 224 | 616 | 88 | N. a. | 1, 045 |
| 1950 | 33 | 232 | 626 | 150 | N. a. | 1, 257 |
| 1951 | 55 | 291 | 750 | 412 | N. a. | 1, 682 |
| 1952 | 77 | 232 | 394 | 322 | N. a. | 1, 292 |
| 1953 | 79 | 264 | 508 | 333 | 26 | 1, 392 |
| 1954 | 106 | 196 | 679 | 404 | 24 | 1, 739 |
| 1955 | 154 | 247 | 1, 058 | N. a. | 19 | 2, 165 |

[1] Estimated.

## CONSUMPTION

United States consumption of cadmium is usually approximately three-fourths of the world total. The United Kingdom is the second largest consumer, using, in recent years, over 1.5 million pounds annually. France, Germany, Canada, and Italy are other leading cadmium consumers. Table 16 shows consumption in some countries for 1941–55.

The consumption pattern in Europe is different from that in the United States. In Europe cadmium batteries have been in wide use for many years; hence, consumption of cadmium for that purpose is relatively large. Table 17 (showing consumption of cadmium in the United Kingdom, by uses, in 1952–55) is illustrative.

TABLE 17.—*Consumption of cadmium in the United Kingdom, 1952–55*

(Pounds)

[British Bureau of Non-Ferrous Metal Statistics, January 1956, and August 1957]

| Use | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|
| Plating anodes | 603, 500 | 566, 200 | 742, 300 | 1, 022, 100 |
| Plating salts | 110, 300 | 101, 800 | 145, 000 | 218, 700 |
| Alloys: | | | | |
| Cadmium-copper | 147, 100 | 115, 000 | 115, 700 | 144, 900 |
| Solder | 48, 300 | 53, 000 | 81, 300 | 85, 700 |
| Other alloys | 41, 200 | 46, 000 | 47, 200 | 64, 800 |
| Batteries: | | | | |
| Alkaline | 157, 700 | 153, 200 | 169, 000 | 177, 400 |
| Dry | 9, 700 | 11, 200 | 10, 200 | 10, 300 |
| Colors | 149, 100 | 200, 400 | 385, 400 | 389, 800 |
| Miscellaneous | 24, 800 | 31, 700 | 46, 700 | 51, 400 |
| Total | 1, 291, 700 | 1, 302, 600 | 1, 739, 500 | 2, 165, 100 |

## TRADE

Information on the volume of trade in cadmium between foreign countries is incomplete and, in some instances, conflicting. Nevertheless, available data do show the relative position, with respect to supplies of cadmium, of the more important producing and consuming countries.

TABLE 18.—*Imports of cadmium of selected European countries, 1945–55*

(Thousand pounds)

[Minerals et métaux, Société anonyme, Statistiques, 1950, 1956]

| Year | Belgium-Luxembourg | France | Germany | Italy | Sweden | United Kingdom |
|---|---|---|---|---|---|---|
| 1945 | N. a. | 49 | ..... | ..... | 43 | 839 |
| 1946 | 27 | 475 | ..... | ..... | 143 | 835 |
| 1947 | N. a. | 315 | ..... | ..... | 127 | 781 |
| 1948 | 40 | 352 | ..... | ..... | 193 | 1, 042 |
| 1949 | 27 | 484 | 79 | ..... | 291 | 686 |
| 1950 | 40 | 372 | 134 | ..... | 236 | 1, 089 |
| 1951 | 33 | 620 | 29 | ..... | 214 | 1, 492 |
| 1952 | 22 | 200 | [1] 186 | 35 | 249 | 1, 391 |
| 1953 | 29 | 226 | [1] 403 | 21 | 174 | 940 |
| 1954 | 49 | 367 | [1] 633 | 10 | 295 | 1, 636 |
| 1955 | 63 | 663 | [1] 788 | [2] | 192 | 1, 922 |

[1] Statistical Summary of the Mineral Industry, 1950–55, Colonial Geological Surveys, H. M. Stationery Office, London, 1957, p. 61.
[2] Less than 1,000 pounds.

The United Kingdom, the second-ranking consumer of cadmium, depends wholly on imports for its industry needs. Substantial quantities of cadmium contained in imported Australian zinc ores and concentrates are recovered in the United Kingdom, but most of the country's requirements are fulfilled through

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TABLE 19.—*Exports of cadmium of selected foreign countries (domestic produce), 1945–55* [1]

(Thousand pounds)

[Statistical Summary of the Mineral Industry, 1949–54, Colonial Geological Surveys, H. M. Stationery Office, London, 1956, p. 57; Minerais et métaux, Société anonyme, Paris, France, Statistiques, 1953 and 1956]

| Exporting country | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 |
|---|---|---|---|---|---|---|
| Australia | 506 | 298 | 215 | 195 | 390 | 383 |
| Belgian Congo | 26 | 7 | N. a. | N. a. | N. a. | 70 |
| Belgium-Luxembourg | 18 | 220 | N. a. | N. a. | 999 | 1,003 |
| Canada | 350 | 592 | 618 | 596 | 634 | 676 |
| Italy [1] | ---------- | 44 | 44 | 44 | 88 | 17 |
| Mexico [2] | 2,321 | 1,581 | 1,661 | 1,997 | 1,733 | 1,518 |
| Norway | 2 | 48 | 94 | 81 | N. a. | N. a. |
| Peru | 2 | 5 | 3 | 4 | 2 | 3 |
| Poland | 88 | 221 | N. a. | N. a. | N. a. | N. a. |
| South-West Africa [3] | N. a. | N. a. | N. a. | 896 | 1,670 | 1,534 |
| United Kingdom | 112 | 83 | 5 | 5 | 6 | N. a. |

| | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|
| Australia | 298 | 307 | 634 | 385 | 374 |
| Belgian Congo | 55 | 43 | 70 | 68 | 309 |
| Belgium-Luxembourg | 324 | 121 | 169 | 319 | 316 |
| Canada | 825 | 620 | 969 | 770 | 1,417 |
| France | ---------- | ---------- | 1 | 1 | 3 |
| Italy [2] | 32 | 3 | 90 | 64 | 906 |
| Mexico [3] | 1,971 | 1,618 | 2,113 | 1,130 | 2,855 |
| Norway | N. a. | N. a. | 237 | 133 | N. a. |
| Peru | N. a. | N. a. | 11 | 31 | 34 |
| Poland | N. a. | N. a. | N. a. | N. a. | N. a. |
| South-West Africa [3] | 752 | 1,024 | 1,008 | 684 | 1,404 |
| United Kingdom | 4 | 17 | 20 | N. a. | N. a. |

[1] Includes scrap.
[2] Cadmium content of flue dust.
[3] Cadmium content of concentrates exported for treatment.

TABLE 20.—*United Kingdom imports of cadmium, by countries, 1941–55*

(Thousand pounds)

[Minerais et métaux, Société anonyme, Paris, France, Statistiques, 1950 and 1956]

| Year | Australia | Belgium-Luxembourg | Canada | United States | Other | Total |
|---|---|---|---|---|---|---|
| 1941 | 340 | ---------- | 854 | ---------- | ---------- | 1,194 |
| 1942 | 179 | ---------- | 817 | ---------- | ---------- | 996 |
| 1943 | 125 | ---------- | 194 | ---------- | ---------- | 319 |
| 1944 | 124 | ---------- | 329 | ---------- | ---------- | 453 |
| 1945 | 452 | ---------- | 385 | ---------- | 2 | 839 |
| 1946 | 335 | ---------- | 498 | ---------- | 2 | 835 |
| 1947 | 245 | ---------- | 501 | 30 | 5 | 781 |
| 1948 | 330 | ---------- | 585 | 115 | 12 | 1,042 |
| 1949 | 183 | ---------- | 429 | 47 | 27 | 686 |
| 1950 | 380 | 207 | 381 | 99 | [1] 22 | 1,089 |
| 1951 | 316 | 304 | 755 | 110 | [2] 7 | 1,492 |
| 1952 | 301 | 125 | 583 | 382 | ---------- | 1,391 |
| 1953 | 285 | 296 | 358 | ---------- | 1 | 940 |
| 1954 | 423 | 198 | 601 | 414 | ---------- | 1,636 |
| 1955 | 377 | 130 | 581 | 834 | ---------- | 1,922 |

[1] Japan.
[2] Sweden, 5,000 pounds; Japan, 2,000 pounds.

imports of metal, principally from Canada and Australia.

Belgium is an important producer of refined metal and since 1949 has been the leading exporter of cadmium. Shipments principally are destined to European countries and the United States. During the 5 years 1949–53 the United States received nearly 2 million pounds from Belgium. In 1949–51 Belgium exported about 900,000 pounds of cadmium to the U. S. S. R.

Other more important cadmium producers and consumers in Western Europe include France, Germany, the Netherlands, and Sweden, which are leading importers, and Norway and Italy, which are relatively important exporters. Tables 18 to 23 give some indication of the scope of foreign trade in cadmium.

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TABLE 21.—*Cadmium imports of France, by countries, 1941–55*

(Thousand pounds)

[Minérais et métaux, Société anonyme, Paris, France, Statistiques, 1950 and 1956.]

| Year | Australia | Belgium-Luxembourg | Canada | Germany | Italy | Norway | United Kingdom | United States | Other | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1941 | | | | 27 | | | | | | 27 |
| 1942 | | | | 56 | | | | | | 56 |
| 1943 | | | | 31 | | | | | | 31 |
| 1944 | | | | | | | | | | |
| 1945 | | 4 | | | | | | 45 | | 49 |
| 1946 | 22 | 108 | 67 | | 52 | | 151 | 75 | | 475 |
| 1947 | 22 | 97 | 57 | | 32 | 33 | | 62 | [1] 12 | 315 |
| 1948 | | 55 | 30 | | 55 | | | 203 | [2] 9 | 352 |
| 1949 | 70 | 98 | 52 | | | 66 | | 198 | | 484 |
| 1950 | 41 | 152 | 10 | | | 44 | | 120 | [3] 5 | 372 |
| 1951 | 14 | 251 | 21 | | 11 | 154 | | 169 | | 620 |
| 1952 | | 40 | 23 | | 3 | | | 134 | | 200 |
| 1953 | 71 | 71 | | | 14 | 34 | 4 | 10 | [4] 22 | 226 |
| 1954 | 16 | 263 | | 2 | 45 | | | | [5] 41 | 367 |
| 1955 | 4 | 542 | | 25 | 46 | 22 | 9 | 11 | [6] 4 | 663 |

[1] French Equatorial Africa, 10,000 pounds; Switzerland, 2,000 pounds.
[2] French Equatorial Africa, 400 pounds; Japan, 8,200 pounds.
[3] Belgian Congo, 4,400 pounds; Switzerland, 900 pounds.
[4] Belgian Congo.
[5] Belgian Congo, 15,200 pounds; Japan, 25,300 pounds.
[6] Peru.

TABLE 22.—*Cadmium exports of Canada, by countries, 1949–55* [1]

(Thousand pounds)

[Bureau of Mines, Division of Foreign Activities]

| | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|---|---|
| Belgium | 26 | | | | | | 22 |
| Brazil | | | 3 | | | (2) | |
| France | 35 | 20 | 34 | 11 | | | |
| Germany | | | 11 | | | | 34 |
| Netherlands | 15 | 17 | | | | 45 | 78 |
| Sweden | 49 | 38 | 22 | | | | |
| Switzerland | 2 | 2 | 5 | | | | |
| United Kingdom | 442 | 367 | 745 | 594 | 358 | 561 | 609 |
| United States | 65 | 232 | 5 | 15 | 611 | 163 | 674 |
| Chile | | | | | | 1 | |
| Total | 634 | 676 | 825 | 620 | 969 | 770 | 1,417 |

[1] Less than 1,000 pounds to India 1952 and 1955; Mexico, 1951; New Zealand, 1949, 1951, 1953.
[2] Less than 1,000 pounds.

TABLE 23.—*Cadmium exports of Belgium-Luxembourg, by countries, 1949–55*

(Thousand pounds)

[Minerais et métaux, Société anonyme, Statistique, 1950 and 1956]

| Destination | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|---|---|
| Denmark | | | | 4 | | 47 | 30 |
| France | 163 | 73 | 79 | 20 | 55 | 134 | 129 |
| Germany | 79 | 134 | 18 | 7 | 9 | 22 | 19 |
| Netherlands | 66 | 84 | 40 | 11 | 22 | 79 | 99 |
| Sweden | 49 | 71 | 18 | | | 4 | 5 |
| Switzerland | | | 18 | 11 | 11 | 11 | 9 |
| United Kingdom | 46 | | 53 | 13 | 22 | 22 | 14 |
| U. S. S. R. | 470 | 392 | 35 | | | | |
| United States | 49 | 97 | 48 | 55 | 35 | | 11 |
| Others | 77 | 152 | 15 | | 13 | | |
| Total | 999 | 1,003 | 324 | 121 | 167 | 319 | 316 |

# STRUCTURE OF UNITED STATES CADMIUM INDUSTRY

The cadmium industry of the United States is composed of four segments—primary producers, secondary producers, distributors, and consumers. On the production side, primary producers are of preponderant importance, accounting for more than 95 percent of total annual output.

## PRIMARY PRODUCERS

Primary cadmium production is closely related to and depends largely upon activities in the zinc industry and (to a much smaller extent) the lead and copper industries. Cadmium is recovered almost exclusively from zinc operations as a highly valuable byproduct. The relationship is such that cadmium production constitutes an integral part of the zinc industry. The cadmium operations of the zinc industry, however, are not comparable in value to zinc operations; recovery of cadmium is not on a coproduct basis and therefore, from an overall standpoint of the zinc industry, has secondary importance. This is not meant to infer that the cadmium industry is unimportant but merely to emphasize its relation to the zinc industry.

The primary producers of cadmium are, without exception, leading zinc producers. In 1955, 11 companies produced primary metallic

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cadmium at 13 plants in the United States. The largest producer is the American Smelting & Refining Co. Other large producers include the American Zinc Co. of Illinois, The Anaconda Company, Blackwell Zinc Co., National Zinc Co., Inc., The Bunker Hill Co., St. Joseph Lead Co., and Eagle-Picher Co.

Of the 13 cadmium-recovery units active, 9 are operated in conjunction with zinc plants, 2 small units are located at lead smelters and refineries, and 1 small plant treats residues from a zinc-pigments plant. These plants treat both domestic and foreign ores and concentrates; hence, the byproduct cadmium is of mixed origin. Only one plant—the American Smelting & Refining Co. unit at Denver (Globe), Colo.—is operated chiefly to recover cadmium. This plant (the largest in the world) works chiefly on cadmium flue dust from company operations in Mexico. Table 24 lists the primary domestic producers, plants, and annual rated capacity.

TABLE 24.—*Primary metallic cadmium production capacity in the United States in 1955*

| Company | Location of plant | Annual capacity, thousand pounds [1] |
|---|---|---|
| American Smelting & Refining Co. | Denver, Colo. | [2] |
| | Corpus Christi, Tex. | [2] |
| American Zinc Co. of Illinois | Fairmont City, Ill. (East St. Louis). | 1,250 |
| The Anaconda Company | Great Falls, Mont | 2,000 |
| Blackwell Zinc Co. | Blackwell, Okla. | [3] |
| National Zinc Co., Inc. | Bartlesville, Okla. | 720 |
| The Bunker Hill Co. | Kellogg, Idaho | 600 |
| Eagle-Picher Co. | Henryetta, Okla. | 400 |
| New Jersey Zinc Co. | Depue, Ill. | 250 |
| United States Steel Corp. (American Steel & Wire Div.). | Donora, Pa. | [2] |
| St. Joseph Lead Co. | Herculaneum, Mo. | 300 |
| | Josephtown, Pa. | 300 |
| Sherwin Williams Co. | Coffeyville, Kans. | [2] |
| Total | | [4] 12,000 |

[1] Largely estimated; rated capacity is flexible, depending to a great extent on the quantity and grade of raw materials available.
[2] Concealed to avoid disclosure of individual plant capacity.
[3] Not available.
[4] Approximate.

Several zinc- and lead-producing plants that do not produce refined cadmium have facilities for collecting cadmium fume, dust, sponge, or residues. These companies either sell the cadmium-containing material to the cadmium producers, have it treated for them on a toll basis, or transfer it to other company-owned plants that produce cadmium metal. They include the American Zinc Co. of Illinois, Monsanto, Ill., and Dumas, Tex.; Matthiessen & Hegeler Zinc Co., LaSalle, Ill.; American Smelting & Refining Co., Amarillo, Tex., and Alton, Ill.; Athletic Mining & Smelting Co. and the Residue Co., both at Fort Smith, Ark.; New Jersey Zinc Co., Canon City, Colo., and Palmerton, Pa.; International Smelting & Refining Co., Tooele, Utah; and the United States Smelting, Refining & Mining Co., Midvale, Utah. Custom smelters as a rule do not pay shippers of zinc and/or lead ores and concentrates for contained cadmium values. However, during periods of competitive bidding for zinc concentrates, smelters have occasionally paid for cadmium values. Only a few companies have cadmium toll agreements with a smelter.

Two companies—the American Smelting & Refining Co. and Harshaw Chemical Co.—produce relatively small quantities of cadmium compounds from primary raw materials at their Denver (Colo.) and Elyria (Ohio) plants, respectively. Being of primary origin, such production is an addition to the new supply.

## SECONDARY PRODUCERS

Recovery of cadmium metal and compounds from scrap materials constitutes a comparatively minor segment of the cadmium industry. Several companies produce the metal and compounds, principally from old bearings and other alloys and secondary residues, respectively. Recovery of the metal and production of compounds (not produced from secondary metal) are an addition to the total supply of cadmium. Following is a list of producers and plants:

| | | |
|---|---|---|
| Arkansas Metals Co. | Jonesboro, Ark. | Secondary metal. |
| National Zinc Co., Inc. | Bartlesville, Okla. | Do. |
| Neo-Smelting & Refining Inc. | Whitestone, N. Y. | Do. |
| United Smelting & Refining Corp. | Chicago, Ill. | Do. |
| Harshaw Chemical Co. | Elyria, Ohio | Secondary compounds. |
| Chemicals-Pigments-Metals, Division of Glidden Co. | Baltimore, Md. | Do. |

The Arkansas Metals Co. and Neo-Smelting & Refining, Inc., also perform the function of distributors, buying domestic cadmium and importing foreign metal for remelting, purifying, and casting into special shapes that usually command a premium price on the market.

## DISTRIBUTORS

Ordinarily primary cadmium producers account for two-thirds of the sales to consumers; most of them sell the metal themselves. However, the St. Joseph Lead Co. acts as sales agent for the Bunker Hill Co. in territory east of the 95th meridian.

The distributors buy the metal at reduced prices from the primary producers and sell to consumers. About one-third of the sales to con-

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sumers is made by distributors. Cadmium distributors in the United States are composed of two groups: (1) The companies that, for the most part, produce plating salts, supply special platers' shapes of cadmium as well as regular grades, and provide technical service for their customers who are chiefly electroplaters; and (2) buyers of domestic and imported cadmium for resale. In the first group the most important dealer is the Udylite Corp., Detroit, Mich. Following is a list of the companies in the first group engaged in distributing cadmium in 1952:

| | |
|---|---|
| Udylite Corp. | Detroit, Mich. |
| E. I. du Pont de Nemours & Co. (Methods Div.). | Wilmington, Del. |
| Lea Manufacturing Co. | Waterbury, Conn. |
| Harrison-Van Winkle-Munning Co. | Matawan, N. J. |
| McGean Chemical Co. | Cleveland, Ohio. |
| MacDermid, Inc. | Do. |

Distributors in the second group in 1952 included the following:

| | |
|---|---|
| Associated Metals & Minerals Corp. | New York, N. Y. |
| Balex Co., Inc. | Do. |
| Belmont Smelting & Refining Works, Inc. | Brooklyn, N. Y. |
| Bandeis Goldschmidt & Co., Inc. | New York, N. Y. |
| Cambridge Street Metal Co., Inc. | Boston, Mass. |
| Cosmo Metal Alloys, Corp. | New York, N. Y. |
| Industrial Sales Corp. | Do. |
| Interocean Chemical & Minerals Corp. | Do. |
| Mercantile Metal & Ore Corp. | Do. |
| Miles Metal Corp. | Do. |
| Northwest Lead Co. | Seattle, Wash. |
| Overseas Metal & Ore Corp. | New York, N. Y. |

Metal Statistics, published by the American Metal Market, 18 Cliff St., New York 38, N. Y., and Thomas' Register of American Manufacturers, published by the Thomas Publishing Co., New York 1, N. Y. list other sellers of cadmium.

## CONSUMERS

There are thousands of consumers of cadmium in the United States, most of whom use relatively small quantities of the metal. The largest group of consumers is composed of companies that use the metal for electroplating various manufactured products. Bearing manufacturers, pigment producers, and solder makers are the other principal consuming industries. Three companies—the Chemicals-Pigments-Metals Division of the Glidden Co., Baltimore, Md.; Harshaw Chemical Co., Elyria, Ohio; and Kentucky Color & Chemical Co., Louisville, Ky.—consumed the bulk of the metallic cadmium used in pigment making. In the other major consuming groups, particularly electroplating, there is no apparent concentration of consumption among a few companies; there are numerous consumers that use quantities ranging from less than 100 pounds to 100,000 pounds a year.

In 1952 a partial survey of cadmium consumers disclosed that approximately 125 companies used about 3.5 million pounds of cadmium, or slightly less than 40 percent of the total consumption during the year. All companies used 5,000 or more pounds during the year, and 19 of them used over 30,000 pounds each and consumed about 2.2 million pounds of cadmium in all. This study was by no means complete as the names of customers of several producers and many distributors were not available.

The Federal Government purchased large quantities of cadmium for the national stockpile in 1948–52 and was by far the principal buyer of the metal during those years. Buying for the minimum stockpile requirement was completed in 1955.

The major consuming centers of cadmium in the United States are the highly industralized areas in the Northeastern and East North Central States. In particular, the Chicago, Detroit, Cleveland, Baltimore, and Waterbury (Conn.) areas are leading consuming regions. Other outstanding consuming centers include Milwaukee, Los Angeles, Pittsburgh, Philadelphia-Camden, New York-Newark, St. Louis, Toledo, Buffalo, Worcester, and Providence.

# FOREIGN INDUSTRY OPERATIONS

The composition of the cadmium industry in foreign countries is similar to the makeup of the industry in the United States; it consists of primary producers, secondary producers, distributors, and consumers. The primary producers are, for the most part, the leading producers of zinc and, to a smaller extent, lead. There are plants at zinc smelters, electrolytic zinc plants, and lead smelters. Producers sell their cadmium either directly to consumers or to metal dealers. A list of the principal foreign producers follows:

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TABLE 25.—*Principal foreign producers of cadmium* [1]

[Principally from Minérais et métaux, Société anonyme, Paris, France, Statistiques, 1953, July 1954, p. 98] [1]

| Country: | *Company* | *Location of plant* |
|---|---|---|
| Australia | Electrolytic Zinc Co. of Australasia, Ltd | Risdon (Tasmania). |
| | Broken Hill Associated Smelters Pty., Ltd | Port Pirie (South Australia). |
| Belgium | S. A. Métallurgique de Prayon | Prayon-les-Trooz. |
| | S. A. des Mines et Fonderies de Zinc de la Vieille-Montagne. | Balen Wezel. |
| | Cie des Métaux d'Overpelt-Lommel & de Corphalie | Overpelt. |
| Belgian Congo | Sté Générale Industrielle & Chimique du Katanga "Sogechim" (Union Miniére de Haut Katanga). | Jadotville. |
| Canada | Hudson Bay Mining & Smelting Co., Ltd | Flin Flon (Manitoba). |
| | Consolidated Mining & Smelting Co. of Canada, Ltd | Trail (British Columbia). |
| France | S. A. des Mines et Fonderies de Zinc de la Vieille-Montagne. | Viviez (Aveyron). |
| Germany, West | "Berzelius" Metallhütten G. m. b. H | Duisberg-Wanheim/Rhein. |
| | Unterharzer Berg-und Hüttenwerk G. m. b. H | Harlingerode/Harz. |
| | "Sachtleben" A. G. für Bergbau und chemische Industrie. | Hamburg/Niederrhein. |
| Italy | Sta Mineraria e Metallurgica di Pertusola | Vrotone (Calabria). |
| | Sta di Monteponi | Monteponi (Sardinia). |
| | Sta Montevecchio Italiana del Piombo e dello Zinco | Porto Marghera (Venice). |
| Japan | Mitsubishi Metal Mining Co., Ltd | Hosokura (Miyagi). |
| | | Naoshima (Kagawa Shikoku I.). |
| | Mitsui Mining & Smelting Co., Ltd | Hikoshima (Yamaguchi). |
| | | Kamioka (Gifu). |
| | | Miike (Fukuoka Kyusbu I.). |
| | Nippon Soda Co., Ltd | Aizu (Fukushima). |
| | Toho Zinc Co., Ltd | Annaka (Gumma). |
| Mexico | American Smelting & Refining Co.[2] | San Luis Potosi (San Luis Potosi). |
| | | Rosita (Coahuila). |
| | | Chihuahua (Chihuahua). |
| | American Metal Co., Ltd.[2] | Monterrey (Nuevo Leon). |
| | | Torreon (Coahuila). |
| Peru | Cerro de Pasco Copper Corp | Oroya. |
| Norway | Det Norske Zinkkompani A/S | Eitrhein (Odda). |
| Spain | Cie Royale Asturienne des Mines | Arnao. |
| United Kingdom | Imperial Smelting Corp. Ltd | Avonmouth (Bristol). |

[1] Excludes Poland and U. S. S. R.
[2] Production is cadmium flue dust which is shipped to the United States for recovery of metal.

Some of the leading foreign distributors of cadmium as listed in Metal Statistics—1953, published by the American Metal Market, 18 Cliff St., New York 38, N. Y., are shown below:

| | |
|---|---|
| Bass, de Conick & Co., S. A. | Brussels, Belgium. |
| Emile Janssens | Do. |
| W. W. Wiedmann & Co | Antwerp, Belgium. |
| Henry Gardner & Co., Ltd. | London, E. C. 3, England. |
| The British Metal Corp | London, England. |
| N. V. Womet | Amsterdam-C, Netherlands. |
| Société anonyme des métaux et minérais. | Lausanne, Switzerland. |
| Mitsubishi Metal Mining Co., Ltd. | Tokyo, Japan. |
| Mitsui Mining & Smelting Co., Ltd. | Do. |
| The Muromachi Bussan Kaisha, Ltd. | Do. |

Information is not available on producers of secondary cadmium in foreign countries. Consumers are, as in the United States, numerous and, except for battery manufacturers, use cadmium for the same purposes as do United States concerns. Industrialized centers are the principal consuming areas.

# GOVERNMENT CONTROLS

The Government regulated the cadmium industry during World War II and again in 1951–52, in order to provide adequate supplies for all essential purposes. Cadmium was on the critical metals list throughout the entire war period and under Public Law 520, 79th Congress, 1946, was classified as a strategic and critical material for stockpiling.

## WORLD WAR II

The maintenance of cadmium production in the United States and direction of available supplies into war channels were undertaken by the Cadmium Section, Office of Production Management (OPM) in 1941. During the second half of 1941 producers freely marketed

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cadmium, although OPM watched deliveries and handled individually the bad situations that developed. Cadmium was placed under full priority control by OPM Order M–65 on January 17, 1942. The companion Order M–65–a, issued at the same time, prohibited the use of cadmium in automotive, trailer, and tractor equipment, building supplies and hardware, house furnishings and equipment, and a number of miscellaneous products. Order M–65 was modified by an amendment, effective June 24, 1942, that enabled the War Production Board (WPB) to allocate all cadmium for absolutely essential purposes. OPM Order M–63 (December 28, 1941) provided for the control of cadmium imports but was revoked by Amendment 3 (effective March 14, 1942), because such imports were controlled by other means.

Price controls were instituted early in 1942 because of the tight supply position in 1941 and the imminent possibility of shortages. During the last three quarters of 1941 primary producers of cadmium had indicated their willingness to continue to sell the metal to consumers at prices not above 90 cents a pound for sticks and 95 cents for anodes and to sell to distributors at discounts permitting resales at the same prices. Compliance with this agreement, which was adhered to by primary producers but not by certain secondary producers, was made mandatory by Office of Price Administration (OPA) Price Schedule 71, effective January 19, 1942. The order was amended, effective June 22, 1942, to permit the sale of metallic cadmium in small containers (5 pounds or less) at October 1941 price levels. The OPA fixed ceiling prices on partly used anodes at 94 cents a pound, cadmium oxide at 95 cents a pound, and cadmium scrap at 35 cents per pound of contained cadmium, effective October 21, 1942 (Order 6, Maximum Price Regulation 204). The maximum prices were f. o. b. plant of the Udylite Corp., Detroit, Mich., which was appointed by the Government-owned Metals Reserve Company, a subsidiary of the Reconstruction Finance Corporation, as its agent to assist in the cadmium stockpiling program and in the redistribution of idle or frozen materials. Price ceilings remained in effect until July 1946.

Cadmium was one of the few nonferrous metals to remain in a critical position in 1943. In the latter half of 1943 there was a significant increase in the consumption of cadmium for bearings and chemicals and a decided decrease in cadmium consumption for electroplating, solders, and alloys. On July 26, 1943, the WPB issued Conservation Order M–65–a, as amended, to prohibit the use of cadmium in pigments, except for specific purposes, most of which were military.

Cadmium continued to be among the most critical materials throughout 1944, and close control was maintained by the WPB through General Preference Order M–65. Although both production and imports were greater than in 1943, increased military requirements and larger exports caused a net decline in stocks. The stepped-up rocket program, plus the continued need for cadmium in tank and aircraft parts, precluded any increase in civilian supply.

Cessation of hostilities in 1945 brought little relief to cadmium consumers. Distribution of the metal was dominated by military demand for the first half of the year; but rapid reconversion to peacetime uses, particularly plating and the production of pigments, called for the metal in quantities greater than the production rate. To help meet this demand, nearly 300,000 pounds of cadmium was released from the Government stockpile to industry. The Government maintained a stockpile of cadmium from 1941 through 1947 for such emergency use. In 1948 all remaining stocks were transferred to the national strategic stockpile as the Government began purchasing cadmium for this reserve.

The WPB and its successor, the Civilian Production Administration (CPA), maintained control of cadmium consumption until August 20, 1945, when General Preference Order M–65 was revoked; however, inventories were limited to 45 days' requirements or a minimum working inventory, whichever was smaller, by Priorities Regulation 32 initiated August 28, 1945.

Cadmium continued under Government control during part of 1946. As a result of expanding consumer demand, limited supply, and a sharp reduction of Government stocks, the CPA on February 1 reinstated control on the consumption of cadmium through provisions of Conservation Order M–389. Order M–389 limited the manufacturers' use of cadmium metal to 90 percent of their consumption in 1941. The limitation on inventories was tightened on February 1, 1946, to 30 days' supply by an amendment to table 1 of Priorities Regulation 32. Continued shortage of cadmium necessitated establishment of a list of essential consumers, and on March 22 the CPA revoked Order M–389 and simultaneously established a specific list of products on which ratings were to be issued for procurement of the metal. Facing a sharp reduction in output of metal because of strikes at zinc smelters producing by-product cadmium, the CPA on May 3 ceased to make further allocations from the Government stockpile, except for emergency use. No additional regulations were issued until July 26, 1946, when all Government controls on cadmi-

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um were terminated with removal of cadmium from price control.

### 1951–52

Following the outbreak of war in Korea in 1950 it appeared that United States supplies of cadmium would be inadequate to meet the demand for both defense and civilian purposes. Hence, on January 1, 1951, the National Production Authority, "in order to insure adequate supplies of cadmium for military uses and essential civilian products for which there is no satisfactory substitute," imposed inventory controls on cadmium and limited the purposes for which cadmium, cadmium-containing items, and cadmium-plated items could be produced. Cadmium Conservation Order M–19 was amended on March 16, April 26, and July 30, 1951, and again on March 13, 1952, relaxing restrictions on the use of cadmium to permit its increased use in a wide range of military and civilian products. Order M–19 was amended because inventories of the metal had been accumulating in the hands of producers pending placement of a larger volume of defense orders. The cadmium order was revoked May 15, 1952, partly because military orders were not as large as had been anticipated and partly because of the greatly increased availability of the metal from record imports.

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